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1893—1896.

SCIENTIFIC RESULTS.

VOLUME III.

We shall be much obliged if the enclosed receipt for it could be signed and forwarded to Prof. W. C. BRØGGER, Christiania.

Christiania. April, 1902.

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Minister of education.

THE NORWEGIAN

NORTH POLAR EXPEDITION 1893—1896

SCIENTIFIC RESULTS

VOLUME III.

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THE NORWEGIAN NORTH POLAR EXPEDITION

1893—1896

SCIENTIFIC RESULTS

EDITED BY

FRIDTJOF NANSEN

VOLUME III

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(Printed March—June 1900.)

IX.

THE OCEANOGRAPHY OF THE NORTH POLAR BASIN

BY

FRIDTJOF NANSEN

(WITH 33 PLATES)

PREFACE.

The present Memoir gives the results of the researches in physical Oceanography made during our expedition. Our main object was to explore the unknown Polar Sea. The oceanographical work outside this area, in the Barents Sea and along the already known Siberian coast, need not be done by a specially built ship like the Fram, and I considered it therefore our duty to sail, with as little loss of time as possible, straight for our main field of operation. Our oceanographical observations on the way could therefore merely be of a very incidental nature. But even our oceanographical work in the North Polar Basin itself is not nearly so complete and accurate as could be desired, and as I now, too late, see that it easily might have been; for a strong ship, frozen fast in the solid ice, drifting slowly across the deep sea, offers in several respects advantages for the most delicate oceanographical investigations, such as are to be found nowhere else. But on the one hand, during an expedition consisting of so few men as we were, there is so much work of various kinds for each man, that no series of investigations can be made so complete as is desirable; on the other hand, through a mistake on my part, we were not prepared for a deep ocean in the north with depths approaching 4000 metres, and we had to make new sounding line and gear for investigating these depths, which hindered our work, especially as the supply of new material was very limited, and we had to be very economical in the use of our line. The most unfortunate circumstance is, however, that when we started on our expedition, the methods employed in oceanographical research were not suffi-

ciently developed as regards accuracy. I myself had previously had little experience in this kind of work. Nevertheless I believed in the necessity of a high degree of accuracy, if valuable results were to be obtained; and in my endeavour to secure a good equipment, I was greatly assisted by some of the first specialists, as will be mentioned later. Experience has, however, taught me the same lesson she has taught so many others; now, when it is too late, I see that it could have been done so much better, instruments and methods could easily have been much improved. I have now learnt that future investigations in physical oceanography will be of little or no value if they are not made with a much higher degree of accuracy than has generally been the case hitherto. In this respect the observations of our expedition form no exception. This is especially unfortunate as they were made in regions where there may be little prospect of having them repeated in the immediate future. The present Memoir will at least prove that this region of the sea is of special interest as regards the circulation of the Ocean. I have, therefore, done my best to make the most out of our observations, but this has necessitated a multitude of controlling experiments and much research afterwards, in order to enable me to correct our observations properly, which has made the preparation of this memoir a very slow and arduous work. These controlling investigations might have been almost entirely avoided, if sufficiently accurate observations and controlling tests had been made during the expedition, with the improved instruments and methods now available; and they would have taken no longer, in spite of the low temperatures and difficult circumstances under which the observations often had to be made. I mention this for the benefit of future expeditions. If I could now repeat our work, I should be able (by the improved water-bottles and thermometers which I have constructed since my return) to determine the temperature of all water-strata with an absolute certainty of 0·01° C.; and their specific gravity could easily be determined with an accuracy of 0·00001 (by the hydrometer of total immersion), and in less time than was spent on our observations. I should now moreover be able to determine fairly accurately, by a properly constructed current-meter, the speed and direction of the currents at the various depths, for the slowly drifting ice offers great advantages in this respect. The North Polar Basin could thus in some ways become the best known region of the Ocean. This ought to be considered by future explorers.

It is my pleasant duty to offer my hearty thanks to those who have assisted me in the preparation of this Memoir. Amongst these I wish especially to mention Mr. HERCULES TORNØE, who has greatly assisted me in my work of determining the corrections of my instruments, especially the hydrometers, Prof. SOPHUS TORUP, in whose laboratory I have made some of the investigations, and Prof. *Otto Pettersson*, who had the great kindness to have controlling tests made at his laboratory in Stockholm.

To Mr. V. WALFRID EKMAN I owe much gratitude for his valuable assistance in solving mathematically several important oceanographical problems, which I asked him to calculate. I may especially mention his calculation of the influence of the Earth's rotation upon the currents produced by the wind (see pp. 370 and 386 *et seq.*).

To Prof. *H. Geelmuyden*, Mr. *Helland-Hansen*, Mr. *O. N. Heidenreich*, Dr. *Johan Hjort*, Prof. *O. Krümmel*, Prof. *H. Mohn*, Mr. *J. W. Sandström*, Prof. *O. E. Schiøtz* and Mr. *Ludvig Schmelck*, I am much indebted for assistance in several ways.

Last, but not least, I offer my sincere thanks to Mr. *Hugh Robert Mill* for his great kindness in reading a proof of this and the following Memoir, and revising the English.

In conclusion I wish to draw attention to the fact that our salinities of the sea-water given in the Memoir are calculated from our specific gravities, $S\,\frac{17{\cdot}5^{\circ}\,C.}{17{\cdot}5^{\circ}\,C.}$, by the factor 1315. They are consequently higher (about 0·08 ‰, see pp. 230, 233) than those obtained by the Swedish and Danish oceanographers by titrations, and between 0·15 ‰ and 0·16 ‰ higher than those obtained according to Knudsen's Tables. (*Martin Knudsen*, 'Hydrographische Tabellen', Copenhagen, 1901). When these excellent Tables appeared in May, 1901, the greater part of the present Memoir was printed, and it was too late to revise our values. I considered it also an advantage to keep them for the present, as they would make our results more comparable with those of previous expeditions.

LYSAKER, *January, 1902.*

FRIDTJOF NANSEN.

ERRATA AND ADDENDA.

The following errors and misprints of importance have been detected in the final impressions. Smaller orthographical errors are not mentioned.

Page 7, line 12, under I, *for* 9·3° C. *read* 9·5° C.

„ 9, first line *et seq.* } These statements are hardly correct, cf. what is said pp. 239—240
„ 10, lines 14 and 15 }

„ 43, line 5. The errors caused by the temperature of the air as well as that of the upper water-strata may have been greater than here assumed, cf. pp. 238—239, and 241—242.

„ 45—47. The temperature-values of the 6th column should have been corrected according to Table 1, p. 240 (for air-temperature see Table pp. 111 *et seq.*), and the values of columns 8 and 9 should be corrected accordingly. The readings of column 8 ought also to be corrected according to Table 3, p. 242. These corrections also neccessitate some alterations in the following discussion, especially pp. 48—49, which, however, is easily seen.

„ 52, *for* the corrections in the Table *read* those of Table 2, p. 241.

„ 53, footnote cf. pp. 237—238.

„ 53, line 6, cf. p. 237.

„ 53—56. The Tables and the figures in the text should be corrected in the same manner as stated above for pp. 45—47.

„ 56, *for* the corrections in the upper Table *read* those of Table 2, p. 241.

„ 66. The Latitudes and Longitudes during the voyage from July 21st to September 22nd, 1893, for every hour of this Table, pp. 66—78, may be found more correctly in the charts Pl. II, VII—IX. The values given in Columns 3 and 4 are only provisional and approximate. For later dates, the exact localities may be found from Prof. Geelmuyden's charts of the Fram's track in vol. II.

„ 75, last line, *for* 1·0 and 0·9 *should probably be read* −1·0 and −1·1.

„ 108. The values of columns 12 and 13 of the Table, pp. 108—131 should be corrected according to Tables 1—3, pp. 240—242. The more correct values thus obtained are given in the Table on pp. 244—256, 5th column.

„ 108. Latitude and Longitude of the soundings are given more correctly in the Table on p. 244.

„ 108, 4th column 2 lines from foot, *for* 57° *read* 51°.

„ 118, 2nd column, lines 4 and 5, *for* June 26 ca. 8 p. m. *read* June 22.

„ 125, 13th column, last two lines, *for* 1·68 and 1·67 *read* −1·68 and −1·67.

„ 127, 14th column, last line, *for* 14th *read* 13th.

„ 128, 14th column, lines 2 & 3 from foot, *omit* with Pettersson's water-bottle.

Page 129, 5th column, line 5, *for* 1·0° C. *read* −1·0° C.
„ 158–161. The Latitudes and Longitudes from Aug. 12th to Sept. 22nd, 1893, may be found more correctly in the charts, Pls. VII–IX, than in the 3rd and 4th column of this Table.
„ 158, Aug. 22, 8 p. m., 5th column, *for* 1·0 *read* −0·1.
„ 158, Aug. 24, *for* 8– *read* 8 a. m.
„ 160, Sept. 11, Midn., 5th column, *for* 0·9 *should probably be read* −1·1.
„ 160, „ „ „ last column, *for* 2451 „ „ „ 2458.
„ 166, 2nd column, latitudes and longitudes are given more correctly on p. 244.
„ 167, Aug. 11, 10 m., 6th column. It seems probable that by a slip of the pen 2010 has here been recorded instead of 2310. The values in the 9th and 10th columns would then be 1·02330 and 30·64.
„ 169, 7th column, 18 lines from foot. *for* 2833 *read* 2633.
„ 180, last column, 3 lines from foot, *for* 35·22 *read* 35·32.
» 183, last column, 4 lines from foot, *for* 34·74 *read* 34·47.
„ 186, last column, first line, *for* 32·23 *read* 33·23.
„ 186, last column, last line, *for* 34·67 *read* 34·87.
„ 189, first column, last section, *insert* **23.**
„ 193, 7th column, 2 lines from foot, *for* 2548 *read* 2648.
„ 195, 7th column, line 13, *for* 2678 *read* 2578.
„ 245, Aug. 11, 10 m., 6th–8th columns, *for* 2030 | 26·68 | 2139 *ought probably to be read* 2330 | 30·64 | 2453.
„ 246, 7th column, 3 lines from foot, *for* *35·22 *read* 35·22.
„ 248, May 25, 2000 m., 8th column, *for* 2916 *read* 2816.
„ 250, July 11, 5 m., 6th to 9th columns, *for* 2258 | 29·69 | 2379 *read* 2254 | 29·64 | 2375.
„ 252, Nov. 3, 700 m., 6th to 9th columns, *for* 2666 | 35·06 | 2805 *read* 2670 | 35·11 | 2810.
„ 253, May 13, 0 m., 6th to 9th columns, *for* 1·02437 | 32·05 | 1·02568 *read* 1·02386 | 31·37 | 1·02517.
„ 253, May 13, 20 m., 6th to 9th columns, *for* 2463 | 32·39 | 2596 *read* 2468 | 32·45 | 2601.
„ 253, May 22, 850 m., 6th to 9th column, *insert* 2675 | 35·18 | 2814.
„ 253, May 24, 5th column, *for* −0·02 *read* −0·08.
„ 254, July 31, 20 m., 7th column, *for* 33·31 *read* 32·31.
„ 254, July 31, 850 m., 5th column, *for* −0·02 *read* 0·01.
„ 255, 2nd column, under July 22 *insert* 84° 31′ N. and 71° 55′ E. Under July 26 *insert* 84° 30′ N. and 72° 40′ E.
„ 263, line 15, *for* Pl. VI *read* Pl. IV.
„ 268, line 15, *for* 90 *read* 60.
„ 298, 12 lines from foot, *for* eastern *read* western.
„ 304, 15 lines from foot, *for* 70 to 80 *read* 50 to 60.
„ 326, line 10, *for* observed *read* absorbed.
„ 333, foot-note, *for* lines 1 to 4 *read:* A water-particle moving in any horizontal direction with a velocity of 1 kilometre in 2 hours will, owing to the Earth's rotation, have a tendency to be deflected about 0·49 kilometre towards the right in 70° N. Lat., and 0·51 kilometre towards the right in 80° N. Lat. in the same period, if not influenced by other forces.
„ 384, foot-note 2, last line, *for* 384 *read* 386.

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PART 1.

THE TEMPERATURE OF THE WATER IN THE NORTH POLAR BASIN.

The plan of the Norwegian North-Polar Expedition, 1893—1896, was to a very great extent based upon our previous knowledge of the hydrographic conditions of the North Polar Sea, and more especially upon certain theories which I had formed of the currents (or the drift of the ice) across the North Polar region, which I expected to be an extensive sea. It is therefore only natural that the oceanography of this sea should be of special interest to the expedition, and much attention was paid to the equipment for oceanic research. Thanks to the valuable assistance given by various authorities, it may be said to have been very good in several respects; and I take this opportunity to express my hearty thanks to Prof. *Otto Pettersson,* to Mr. *Hercules Tornøe,* and to Prof. *H. Mohn* for the kind way in which they assisted me in my endeavour to secure an equipment which should ensure a high degree of accuracy in the oceanic researches on the unknown sea which we were going to traverse.

As it was to be expected that the variations of temperature would be comparatively very small in this sea — probably not exceeding a few degrees centigrade — and as these variations, however small they might be, might give important information about the circulation in this part of the ocean, I considered it specially important to be enabled to determine the water temperatures with a higher degree of accuracy than had until then generally been attained in deep-sea research.

I.

INSTRUMENTS.

It is, in my opinion, a matter of much regret that the oceanic research of our day has not kept pace in accuracy with the development of physical determinations. This is especially true with regard to deep sea temperatures, which are very far from satisfying our modern demands for accuracy. We have decidedly not done our best to utilize for oceanography the present high development of thermometry, which could enable us to measure temperature at least to within ± 0·01° C.; but this is still, as a rule, far from being the case. I fear that 50 years hence, our temperature measurements of the ocean of to-day will not be of much value, as they are not sufficiently accurate. This is so much the more to be regretted, as not only secular changes in the circulation of the sea, but possible secular variations in the temperature of the atmosphere or the surface of the earth can probably be most easily demonstrated by the variations of the mean-temperature of the ocean.

PETTERSSON'S INSULATED WATER-BOTTLE WITH NON-CONDUCTING WATER-JACKETS.

This excellent water-bottle marks an important step forward in oceanic research, as it has the great advantage of taking trustworthy water-samples, both for salinity and gas-analyses, and at the same time giving the temperatures for the lesser depths — down to 200 or 300 metres — with an accuracy hitherto unattained. Instruments made on a similar principle, will cer-

tainly enable us to determine the water-temperature down to a certain depth with a degree of accuracy corresponding to the modern development of thermometry, if only sufficient care is taken, and the necessary corrections are applied (see later).

Prof. Otto Pettersson did me the great favour of having an instrument of this pattern made for me in Stockholm, which proved very valuable for the expedition.

Pettersson has himself described the water-bottle in "The Scottish Geographical Magazine" for June, 1894, pp. 284—286 (Pl. I. figs. 1, 2)[1]. Referring the reader to this description, I need not here enter upon the details of its construction.

I found it to be a very handy and perfect instrument. Arranged, as it was, with a meter-wheel (with registering machinery) and a flexible wire sounding-line of phosphor-bronze or steel, one man alone could in a very short time take a series of temperatures and water-samples simultaneously, down to several hundred metres.

If, however, we try to attain the degree of accuracy mentioned above, the temperature readings have to be reduced by the application of several corrections (besides the correction of the thermometer) in order to find the accurate temperature *in situ*. According to my experience, Pettersson's statement is hardly correct, that the insulation of the water-bottle is sufficient to give directly correct temperatures from depths of as much as 400 or 600 metres, even when there are "great differences between the temperatures of the water-layers."

Corrections necessary on account of the pressure of the water at the various depths.

As the water of the ocean is somewhat compressed by the weight of the overlying water, a water-sample hauled up from a certain depth must consequently expand correspondingly as this pressure is diminished. Thus some heat will be absorbed, and the temperature of the sample must necessarily be somewhat lowered.

---

[1] Otto Pettersson, "A Review of Swedish Hydrographic Research in the Baltic and the North Seas", Scottish Geogr. Mag., June to September, 1894.

Lord Kelvin [1] has found the following formula for the thermal effect of compressing fluids:

$$\Theta = \frac{T \,.\, e \,.\, p}{J \,.\, c_p \,.\, \varrho_o}$$

where Θ is the increase of temperature, T the temperature from absolute zero, expressed in centigrade (*i . e .* $274 + t$), e the cubic expansibility by heat per degree centigrade at the temperature in question, p the pressure in kilograms on the square metre, J the mechanical equivalent of the thermal unit $= 425$ kilogram-metres, c_p the specific heat of the fluid employed, at constant pressure, and ϱ_o the weight in kilograms of one cubic metre of the fluid.

Mr. Joule [2] determined by direct experiments the rise in temperature produced by compression of distilled water, and his results agreed remarkably with the theoretical effect calculated by Lord Kelvin's formula, the mean difference between the observed and the calculated (theoretical) effects being 0·0002 ° C.

No such experiments have been made with sea-water, as far as I know; but by means of the above formula, the rise in temperature produced by the pressure of the water in various depths of the sea can easily be calculated, if we only know the temperature of the water *in situ*.

The product $c_p \,.\, \varrho_o$ we may for practical purposes suppose to be a constant, approximately equal to 960 for ordinary sea-water (with a density of about 1·028).

The deep-sea temperatures of the North Polar Basin vary from about — 1·6° C. near the surface (at 100 metres) to about + 1° C. at some hundred metres depth. For our calculations we will take, approximately, the temperatures found in June, 1894, viz.:

100	metres	— 1·6° C.	at 800	metres	— 0·07° C.
200	„	— 0·3 „	1000	„	— 0·14 „
300	„	+ 0·5 „	1200	„	— 0·37 „
400	„	+ 0·36 „	1400	„	— 0·47 „
500	„	+ 0·27 „	1500	„	— 0·54 „
600	„	+ 0·13 „	2000	„	— 0·75 „

---

[1] W. Thomson, 'On the Dynamical Theory of Heat', etc. Transactions Royal Society of Edinburgh, vol. XX. (1853), p. 283. Proceedings of the Royal Society, 1857, vol. VIII. No 27, p. 566.
See also: Rühlmann, 'Handbuch der Mechan. Wärmetheorie,' vol I. (1876), p. 481.

[2] J. P. Joule, 'On the Thermal Effects of Compressing Fluid,' Philosophical Transactions, vol. 149 (1860), pp. 133—136.

According to Ekman's[1] as well as Tornøe's[2] observations, *e*, the cubic expansibility by heat per degree centigrade, should be:

at $-2{\cdot}0^{0}$ C.	e = 0·000025	at $+0{\cdot}5^{0}$ C.	e = 0·000061
„ $-1{\cdot}5$ „	„ 0·000033	„ $+1{\cdot}0$ „	„ 0·000067
„ $-1{\cdot}0$ „	„ 0·000039	„ $+1{\cdot}5$ „	„ 0·000073
„ $-0{\cdot}5$ „	„ 0·000046	„ $+2{\cdot}0$ „	„ 0·000079
„ $-0{\cdot}0$ „	„ 0·000054		

By these figures we find the rise in temperature produced by the compression of the sea-water, owing to the pressure of the overlying water-strata, to be the following at various depths:

Rise in temperature owing to the compression of the sea-water.

at 100 metres	0·002° C.	at 1200 metres	0·041° C.
„ 200 „	0·007 „	„ 1300 „	0·044 „
„ 300 „	0·013 „	„ 1400 „	0·047 „
„ 400 „	0·016 „	„ 1500 „	0·049 „
„ 500 „	0·020 „	„ 1600 „	0·051 „
„ 600 „	0·023 „	„ 1700 „	0·053 „
„ 700 „	0·026 „	„ 1800 „	0·056 „
„ 800 „	0·030 „	„ 1900 „	0·058 „
„ 900 „	0·033 „	„ 2000 „	0·061 „
„ 1000 „	0·036 „	„ 2200 „	0·065 „
„ 1100 „	0·039 „	„ 2400 „	0·070 „

When a water-sample, taken by the insulated water-bottle, is hauled up from a certain depth of the North Polar Basin, its temperature, owing to the heat absorbed by the expansion of the water, will sink as much as is indicated by the figures given in the table above, and the temperature-reading taken has to be corrected accordingly.[3]

The corrections necessary owing to the influence of the air-temperature.

This spring, 1899, I have made several experiments in order to ascertain whether the water-sample in the central tube of the insulated water-bottle,

[1] Ekman, Kongl. Svenska Vet.-Akad. Handl. 1870, 1.

[2] Tornøe, 'Chemistry, The Norwegian North Atlantic Expedition, 1876–1878', vol. II, pp. 52, 53. Christiania, 1880.

[3] In warmer seas these corrections will naturally be considerably larger. For instance, in the series of temperatures given by Pettersson in Scott. Geogr. Mag. 1894, p. 285, the correction, owing to the pressure, of the temperature 3·95° C. from 400 metres should be as much as about + 0·028° C.

Owing to the heating of the water-sample during the hauling up through warmer water-strata this correction will, however, be reduced, and the correction may even become minus.

changes its temperature appreciably by hanging in air of a different temperature during the reading-off of the thermometer.

The experiments were made thus: — the water-bottle[1] was filled with water on the surface of the sea, the thermometer was inserted, and the water-bottle was then allowed to hang for a shorter or longer time in the surface water in order that the thermometer, as well as the parts of the water-bottle, especially the plates of india-rubber, might take the temperature of the sea-surface. Then the water-bottle was quickly carried into the laboratory, where the temperature of the air was nearly constant, being during the first experiment 14·5° C., the second 14·3° C., and the third 14·1° C.

Three different experiments, marked I, II, and III, gave the following results:

	I. Diff. of $t.$ = 9.3° C.		II. Diff. of $t.$ = 9.3° C.		III. Diff. of $t.$ = 9.1° C.	
	Reading	Rise in $t.$	Reading	Rise in $t.$	Reading	Rise in $t.$
On the sea-surface	4·98° C.		5·03° C.		5·025° C.	
After 1 minute in the laboratory .	4·97 „	−0·01° C.	5·035 „	+ 0·005° C.	5·04 „	+ 0·015° C.
„ 2 minutes „ „ „					5·05 „	+ 0·025 „
„ 3 „ „ „ „			5·04 „	+ 0·01 „	5·065 „	+ 0·04 „
„ 4 „ „ „ „	4·95 „	− 0·03 „	5·045 „	+ 0·015 „	5·08 „	+ 0·055 „
„ 5 „ „ „ „			5·05 „	+ 0·02 „	5·095 „	+ 0·07 „
„ 6 „ „ „ „			5·055 „	+ 0·025 „	5·11 „	+ 0·085 „
„ 7 „ „ „ „			5·065 „	+ 0·035 „	5·12 „	+ 0·095 „
„ 8 „ „ „ „			5·08 „	+ 0·05 „	5·13 „	+ 0·115 „
„ 9 „ „ „ „			5·10 „	+ 0·07 „		
„ 10 „ „ „ „			5·125 „	+ 0·095 „	5·17 „	+ 0·145 „
„ 11 „ „ „ „			5·165 „	+ 0·135 „	5·19 „	+ 0·165 „
„ 12 „ „ „ „			5·21 „	+ 0·18 „		
„ 13 „ „ „ „			5·25 „	+ 0·22 „		
„ 14 „ „ „ „			5·28 „	+ 0·25 „		
„ 15 „ „ „ „	4·99 „	+ 0·01 „	5·36 „	+ 0·33 „	5·32 „	+ 0·295 „
„ 16 „ „ „ „	5·03 „	+ 0·05 „				
„ 17 „ „ „ „						
„ 18 „ „ „ „	5·12 „	+ 0·14 „				
„ 20 „ „ „ „	5·22 „	+ 0·24 „				
„ 22 „ „ „ „	5·31 „	+ 0·33 „				
„ 23 „ „ „ „	5·37 „	+ 0·39 „				
„ 26 „ „ „ „	5·55 „	+ 0·57 „				
„ 29 „ „ „ „			6·25 „	+ 1·22 „		
„ 36 „ „ „ „	6·15 „	+ 1·17 „				

In the first case the water-bottle was left for a considerable length of time in the water before it was carried into the laboratory, so it may be supposed that the different parts of the water-bottle had assumed the temperature of the sea-surface. The sinking of the temperature during the first four minutes in this case, may perhaps to some extent be owing to evaporation of water from the surface of the water-bottle, which was wet for some time, before it was wiped dry[2]. It will be seen that the rise of temperature is very slow

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[1] The water-bottle belonging to Dr. Johan Hjort, was received from Prof. Pettersson, and is of exactly the same size and construction as the one used on board the 'Fram'.

[2] It may perhaps also to some extent be owing to the thermometer having been exposed to the pressure of the overlying water, when the water-bottle was immersed in the sea-surface.

in this case; it is only after 15 minutes that the heating from outside seems to have reached the central tube, and an appreciable rise of 0·01° C. is perceptible; but after that time the rise of temperature becomes comparatively rapid, and similar to what it is in the other cases.

In the second case, the water-bottle had not been left for such a length of time in the sea-water before it was carried into the laboratory, and it is therefore probable that the parts of the water-bottle, especially the plates of india-rubber, had not had sufficient time to be cooled down to the temperature of the water. The result is that the rise of temperature is already perceptible after the first minute, but after 8 or 9 minutes the rate of the rise is very nearly the same as after 15 minutes in the first case.

In the third case the water-bottle was only left for a few moments in the sea before the sample was taken up and carried into the laboratory. The result is that the rise of temperature is considerably quicker from the very beginning.

By these experiments it is proved that in order to obtain accurate water-temperatures, when the difference between the temperature of the air and the sea, or between the different water-strata of the sea are considerable, it is of importance that the water-bottle should remain for some time in the desired stratum before the water-sample is enclosed and hauled up. If this is done, as in the first experiment mentioned above, it may be seen that the temperature of the air, being 9·5° C. higher than that of the water sample, does not influence the reading perceptibly, even after a good many minutes (as much as 6 or 8 minutes), provided that there is no wind.[1]

During most of the series of water-temperatures taken during our expedition, the temperature of the air was more or less lower than that of the water-samples, and sometimes the difference was as much as 20 or 30° C., while at the same time there was generally some wind. It must not, however, be expected, according to the experiments mentioned above, that the air-temperature has lowered the temperature of the inner water-sample considerably during the short time — say one or two minutes — necessary for taking the temperature-reading, provided that the water-bottle was given sufficient time to assume the temperature of the desired water-stratum, before it was closed and hauled up. This was, as a rule, the case, as the water-bottle, with the Negretti and Zambra reversing thermometer attached, was generally allowed 10 minutes in the desired depth, before it was hauled up. I cannot, however, be certain that I have always paid sufficient attention to this matter, as I was at that time unaware of its importance, and the temperature-readings may, therefore, in this manner, on very cold

[1] The above experiments were made in the laboratory where the air is at rest. When it is blowing, the cooling or heating effect of the air must naturally be increased in a certain ratio to the force of the wind. Special experiments ought, therefore, to be made with the water-bottle in this respect.

days, have an error perhaps amounting to 0·02° C. It should also be remembered that if the cooling down of the water in the outer jackets of the bottle has already begun on its way through the upper, colder water-strata, this cooling will be continued in the cold air, and may reach the central tube before the reading is taken.

In 'The Scottish Geograph. Mag.', 1894, p. 286 (foot note), Prof. Otto Pettersson records one of his experiments on the insulating property of the water-bottle. Although the temperature of the air was only about 12° C. higher than that of the water-sample, a change in the temperature of the latter was at least appreciable after the bottle had been in the air for 3 minutes. After 3 minutes, the temperature of the insulated water-sample was 0·01° C. higher than it was $2^1/_2$ minutes after the thermometer was inserted, after $3^1/_2$ minutes it was 0·03° C. higher, and after 4 minutes, as much as 0·07° C. higher. This is a greater change of temperature than in any of my experiments mentioned above. The chief reason is probably that the water-sample was taken from a depth of 400 metres, and the rise in its temperature had probably already commenced on its way up through warmer water-strata near the surface. Perhaps also the water-bottle had not been allowed sufficient time in the depth of 400 metres, for its parts to be cooled down and assume the temperature of that water-stratum. We have seen above that this is of some importance.

The low temperature of the air may also have influenced our temperature-readings of the water in another way. The thermometers used for the water-bottle were rather sluggish, and if their temperature, when inserted, differed much from that of the water-sample, they would require about two minutes to take the temperature accurately. When the air was very cold, however, I did not like to wait too long, for fear that the outer water-layers of the water-bottle should freeze, which would naturally influence the temperature (increasing it), besides spoiling the water-sample. It may therefore happen, that on cold days there has been a tendency to read off the thermometers too early, before they had quite reached the temperature of the water; but the errors caused in this way are certainly not very great; they will, as a rule, hardly exceed 0·01 ° C. or 0·02 ° C.

There is also a possibility that on very cold days, the temperature of the water-sample in the water-bottle may be lowered a little — though it may be a mere trifle — by the insertion of the thermometer, which will be considerably colder than the water, if it has not been heated to the approximate temperature beforehand, and this could not always be done. Moreover, when such a cold thermometer, with the outer tube as much as 9 mm. in diameter (as in our Geissler thermometers), is inserted, it will also open the slits in the upper plates of india-rubber a little, and will thus afford an opportunity

for the cooled water (cooled by the surrounding air, as well as by the thermometer) of the uppermost layers of the water-bottle to sink down along the thermometer, and into the central tube. The influence of this circumstance might especially be expected to be appreciable with the Geissler (Fr. Müller) thermometers Nos. 7 & 6, as the distance between the bulb and zero was there so short, that their bulb reached only a very short distance down below the lid of the central tube of the water-bottle, when temperatures below zero had to be read off.

From the above it may be gathered that the water-temperatures which are taken with Pettersson's insulated water-bottle on very cold days, have, on the whole, a liability to be less accurate than those taken on days when the temperatures of the air and the water approach each other. The errors caused by the low air-temperatures may amount to several hundredths of a degree centigrade, but I should not expect them ever to be more than $-0{\cdot}04^{0}$ C. or say $-0{\cdot}05^{0}$ C., at most, in our series of water-temperatures.

Corrections necessary owing to the cooling or heating influence of the water-strata of different temperatures through which the water-bottle is hauled up.

The maximum depth from which Pettersson's insulated water-bottle gives directly trustworthy temperature-readings, varies naturally with the time required to haul the bottle up, as well as with the quantity of the differences existing between the temperature of the deep water-layer, and that of the water-layers above, through which the bottle has to pass on its way to the surface.

It is evident that some time is required before the influence of the temperature-difference of the surrounding water is carried through the outer non-conducting jackets of the bottle, and reaches the water in the central tube, so that the temperature of the latter is appreciably altered.

It is, moreover, evident that the length of this time must be dependent on the amount of difference between the temperature of the water-sample and that of the surrounding water. But it is also probable that the velocity with which the bottle passes through the water will influence the effect; a greater velocity must increase the cooling or heating of the water-sample during a certain time, as it will bring the surface of the water-bottle in contact with

more molecules of the surrounding water in the same period, and these will take heat from, or give off heat to the water-bottle.

After the influence of the temperature-difference of the surrounding water has once reached the water-sample in the central tube, it is to be expected that the temperature of the latter will change regularly according to a certain mathematical curve, which could be determined by experiments, and which might be expected always to be the same for the same water-bottle, provided that the external conditions are not altered.

In April, 1899, I made several experiments with water-bottles of exactly the same size and pattern as the one used on the 'Fram' expedition, in order to determine this curve, but the results have not been satisfactory, as they show too great variations.

I may mention the following examples:

On April 28, 1899, the water-bottle was filled with fresh water of 7·05° C., and was left hanging quietly in a bath-tub with fresh water of 4·69° C., the temperature-difference consequently being 2·36° C.

I. After 3 minutes, the thermometer of the water-bottle indicated a decrease in temperature of 0·01° C.

„	5	—	—	—	—	0·01 „
„	8	—	—	—	—	0·02 „
„	10	—	—	—	—	0·03 „
„	14	—	—	—	—	0·12 „
„	17	—	—	—	—	0·18 „

In another case, the water-bottle was filled with sea-water of 6·30° C., and was placed in a tub through which fresh water of 4·15° C. was flowing slowly, the temperature-difference thus being 2·15° C.

II. After 8 minutes, the thermometer of the water-bottle showed a decrease in temperature of 0·00° C.

„	11	—	—	—	—	0·02 „
„	13	—	—	—	—	0·04 „
„	18	—	—	—	—	0·15 „
„	20	—	—	—	—	0·24 „
„	22	—	—	—	—	0·31 „
„	24	—	—	—	—	0·39 „

Three experiments were made in the following way. The water-bottle was filled with fresh water, and was left hanging by a long line in a large bath-tub of fresh water, so that the top of the bottle was just at the surface of the water. The water-bottle, during the experiments, was kept constantly swinging like a pendulum in the water, thus causing a rapid motion in the latter. The average temperature of the water in the tub was 4·42° C. during the three experiments. The difference between the temperature of this water, and of that in the water-bottle was 3·87° C. during the first experiment (the latter being higher), in the second experiment 3·07° C., and in the third experiment 2·79° C. The results of the experiments were as follows:

	Decrease of the temperature in the water-bottle.		
	III.	IV.	V.
	First exp. temp.-diff. 3·87° C.	Second exp. temp.-diff. 3·07° C.	Third exp. temp.-diff. 2·79° C.
After 2 minutes	0·00° C.	0·00° C.	0·00° C.
„ 4 „	0·00 „	0·00 „	0·01 „
„ 5 „	0·00 „		0·02 „
„ 7 „	0·05 .		0·06 „
„ 8 „		0·10 „	
After 8½ „	0·12 „		0·06 „
„ 9½ „	0·25 „		
„ 10 „		0·23 „	0·17 „
„ 10½ „	0·30 „		
„ 12 „		0·41 „	0·32 „
„ 12¼ „	0·50 „		
„ 13 „		0·52 „	
„ 14 „		0·62 „	0·47 „
„ 14½ „	0·70 „		

An experiment was made in this way. The water-bottle was filled with sea-water of 7·92° C., and was left for some time in this water, so that its parts assumed the same temperature. The water-bottle was than immersed in the surface of the sea, and there kept in constant, slow motion. The temperature of the sea-surface at the top of the water-bottle was 4·85° C. and at its lower end 5·7° C. The mean temperature of the sea-water surrounding the water-bottle may therefore be assumed to have been 5·3° C,, which gives a temperature-difference inside and outside the water-bottle of 2·6° C.

	Decrease of temperature in the water-bottle.		Decrease of temperature in the water-bottle.
VI. After 1 minute . .	0·00° C.	After 10½ minutes . .	0·27° C.
„ 2 minutes . .	0·00 „	„ 11 „ . .	0·36 „
„ 3 „ . .	0·01 „	„ 12 „ . .	0·44 „
„ 4 „ . .	0·01 „	„ 13 „ . .	0·53 „
„ 5 „ . .	0·02 „	„ 14 „ . .	0·63 „
„ 7 „ . .	0·05 „	„ 15 „ . .	0·72 „
„ 8 „ . .	0·09 „	„ 16 „ . .	0·82 „
„ 9 „ . .	0·16 „	„ 17 „ . .	0·90 „
„ 10 „ . .	0·23 „	„ 18 „ . .	0·97 „

The experiments mentioned above were made with a Pettersson's insulated water-bottle belonging to Dr. Johan Hjort, director of the Norwegian sea and fishery investigations.

On April 19th, 1899, assisted by Dr. Hjort, I made the following experiments at Drøbak on the Christiania Fjord, with an exactly similar water-bottle, also belonging to him.

The temperature of the air was between 6° and 6·5° C. There was very little wind. The temperature of the surface of the sea was 4·36° C. at the beginning of the experiments, and 4·35° C. at their end. The temperature in the various depths of the sea on April 15th was;

	Depth	Temperature
in	0m	4·5° C.
„	10 „	4·6 „
„	25 „	5·8 „
„	50 „	5·8 „
„	80 „	6·1 „
„	120 „	6·1 „

There was no time to determine the temperatures in these depths on April 19th, but they were evidently nearly the same.

The water-bottle was let down to 150 m. along with two Negretti and Zambra reversing thermometers, and was left there for some minutes before it was hauled up. The hauling up took 2 m 30 s. The water-bottle gave a temperature of 6·18° C., whilst both the N. & Z. thermometers gave about two hundredths of a degree higher.

The experiment was repeated in exactly the same way, only that the hauling up this time was very slow, and took 4 m 30 s. The N. & Z. thermometers gave precisely the same temperature, but the water-bottle gave 6·21° C., which was contrary to what was expected. The reason may be either that the thermometer (from Fr. Müller, Bonn) used for the water-bottle, was very sluggish, and required a long time to register, or else that the water-bottle had not been down a sufficiently long time in the first experiment, to allow its parts to fully assume the temperature of the water at that depth. However this may be, the experiments seem to prove that it is practically of little importance for the temperature indication whether the water-bottle is hauled up slowly or rapidly from a depth of no more than 150 m., when the differences between the temperatures of water-layers are no greater than in this case.

An instructive experiment was made in this way. The water-bottle, without the N. & Z. thermometers, was let down to 150 m. and was hauled up at once. The thermometer was inserted, and registered, after nearly two minutes, 6·09° C. The water-bottle, with the thermometer inserted, was left hanging in the surface-water at the bow of the launch, which then went slowly forward. After 3 minutes the thermometer registered 6·11° C. The thermometer had evidently not had sufficient time to register the correct temperature at the first reading, and it shows how important it is that the thermometers used should not be too slow in their action.

The experiment was repeated in such a way, that a new water-sample was taken from 150 m. and hauled up in $2^1/_2$ minutes, the thermometer was inserted and registered 6·20° C. The water-bottle was again closed, and left hanging in the surface-water in front of the bow of the launch, while we went slowly forward. After 10 minutes the thermometer was again inserted, and registered 5·50° C.; there was consequently a decrease in temperature of 0·70° C.

The experiment was repeated in exactly the same manner with a new water-sample from 150 m. When the water-bottle came up, the temperature was 6·17° C., after 4 minutes in the surface-water, the temperature was 6·04° C.; (decrease of $t = 0{\cdot}13°$ C.), and after 8 minutes, it was 5·72° C. (decrease of $t = 0{\cdot}45°$ C.).

The difference of temperature inside and outside the water-bottle in these experiments was 1·83° C., and when we consider them together we find:

		Decrease of t in the central tube of the water-bottle.
VII.	After 4 minutes.	0·13° C.
„	8 „	0·45 „
„	10 „	0·70 „

The reason why the change of temperature is so much greater in these experiments, is evidently to some extent that the water-bottle has already been exposed to colder water-strata during the hauling-up, and then some time has also to be added to the minutes given above, on account of the insertion and reading of the thermometer,

On April 19th, 1899, I also made the following experiments at the Marine Biological Station at Drøbak:

In the laboratory, the water-bottle was filled with sea-water with a temperature of 14·42° C., after the water had been well stirred, and the water-bottle had remained in it for some length of time. The thermometer was inserted through a cork stopper, which made the bottle water-tight. When it was ascertained that the thermometer-reading was constant (14·42° C.), the water-bottle was carried quickly out, and immersed in the surface of the sea at the pier, and there kept in constant motion. The temperature on the sea-surface was 5·03° C.; the temperature-difference inside and outside the water-bottle was thus 9·39° C. The thermometer was read at intervals with the following results:

	Minutes that the water-bottle remained in the sea.	Temperature reading.	Decrease of *t*.
VIII.	1 minute	14·42° C.	0·00° C.
	2 minutes	14·37 „	0·05 „
	3 „	14·29 „	0·13 „
	4 „	14·12 „	0·30 „
	5 „	13·89 „	0·53 „
	6 „	13·53 „	0·89 „
	7 „	13·15 „	1·27 „

The experiment was repeated in the same manner. The temperature of the sea-water in the bottle this time was 13·16° C. The temperature-difference inside and outside the bottle was thus 8·13° C. The results were the following:

	Minutes the water-bottle remained in sea.	Temperature reading.	Decrease of *t*.
IX.	1 minute	13·16° C.	0·00° C.
	2 minutes	13·13 „	0·03 „
	3 „	13·03 „	0·13 „
	4 „	12·90 „	0·26 „
	5 „	12·70 „	0·46 „
	6 „	12·50 „	0·66 „
	7 „	12·17 „	0·99 „
	8 „	11·78 „	1·38 „
	9 „	11·37 „	1·79 „

In order to compare the results of these various experiments with each other, I think it convenient to reduce them all to the same unit. Let us therefore suppose that the effect of the temperature of the surrounding water upon that of the water-sample in the central tube of the water-bottle, is to some extent in a direct ratio to the amount of difference between these two temperatures; we then find that the diminution of temperature, divided by this temperature-difference, should give the diminution of temperature which a temperature-difference of only 1° C. would give in the same length of time. For instance, according to the last mentioned experiment, a temperature-difference,

of 8·13° C. gives a diminution in temperature of 0·46° C. after 5 minutes. A temperature-difference of 1° C. should then, in consequence, after 5 minutes, give a diminution in t of $\frac{0{\cdot}46}{8{\cdot}13}$ ° C. = 0.058 ° C.

By reducing the results of the experiments in this way, we arrive at the following tables, which the same experiments should have given if the temperature-differences had been 1° C. only. The Roman numerals indicate the series of experiments as they have been marked above.

Minutes.	*Decrease of temperature per 1° C. difference of t.*								
	Water-bottle No. 1, at rest.		Water-bottle No. 1, in motion.				Water-bottle No. 2, in motion.		
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
After 1 minute	0·00° C.	0·00° C.	0·00° C.	0·00° C.	0·00° C.	0·00° C.	0·00° C.	0·00° C.	0·00° C.
„ 2 minutes			0·00 „	0·00 „	0·00 „	0·00 „		0·005 „	0·004 „
„ 3 „	0·004 „					0·004 „		0·015 „	0·016 „
„ 4 „			0·00 „	0·00 „	0·004 „	0·004 „	0·07 „	0·03 „	0·03 „
„ 5 „	0·005 „		0·00 „		0·007 „	0·008 „		0·06 „	0·06 „
„ 6 „								0·10 „	0·08 „
„ 7 „			0·013 „		0·02 „	0·02 „		0·14 „	0·12 „
„ 8 „	0·008 „		0·03 „	0·03 „		0·03 „	0·25		0·17 „
„ 9 „						0·06 „			0·22 „
„ 10 „	0·013 „		0·07 „	0·07 „	0·06 „	0·09 „	0·38		
„ 11 „		0·009 „				0·14 „			
„ 12 „			0·13 „	0·13 „	0·11 „	0·17 „			
„ 13 „		0·019 „		0·17 „		0·20 „			
„ 14 „	0·05 „		0·18 „	0·20 „	0·17 „	0·24 „			
„ 15 „						0·28 „			
„ 16 „						0·32 „			
„ 17 „	0·08 „					0·35 „			
„ 18 „		0·07 „				0·37 „			
„ 19 „									
„ 20 „		0·11 „							
„ 21 „									
„ 22 „		0·14 „							
„ 24 „		0·18 „							

By comparing the columns of this table, it will be seen that the experiments have given very different results.

On one hand, there is a striking difference between the results obtained by the two water-bottles No. 1 and No. 2. Although, *e. g.* the results of the two series of experiments, marked VIII and IX, made with the same water-bottle (No. 2), agree very well, they differ widely from the results of the series of experiments marked VI, which were made with the other water-bottle (No. 1), but in exactly the same manner, and which agree well with the series III, IV, and V. I suppose the explanation is that the first-mentioned

water-bottle did not close so tightly as the latter, and thus let in a little of the colder surrounding water during the experiments, which would naturally influence the results very markedly.

On the other hand, there is a marked difference according to whether the water-bottle has been at rest during the experiments, or whether it has been kept in constant motion, *e. g.* experiments I and II compared with experiments III, IV, V, and VI. This is only a confirmation of what might be expected beforehand (see p. 10), as the surface of the bottle is brought by the motion into contact with more water-molecules. It is, however, probable that the motion of the bottle has also another effect, as it will set the water inside the bottle in motion, and thus help to produce currents carrying the heat from the central tube to the surface of the bottle, or *vice versa*. If the water-bottle does not close perfectly tight, the motion will also help the surrounding water to find its way into the outer jackets of the bottle.

It is conceded that these experiments are not fully satisfactory, and it is therefore most desirable that they should be repeated with more accurate and trustworthy methods, in order to determine the rate of the transference of heat through the insulating water-layers of the water-bottle. It cannot be doubted that this rate must be constant, and that it can be determined with a high degree of accuracy, provided that the water-bottle closes perfectly tight. It has, however, been impossible for me to find the time necessary for renewed experiments of this kind. Moreover, they would hardly be of great value for the present Report, as the Pettersson water-bottle used on the expedition was lost, and the experiments mentioned above indicate that such experiments ought to have been made with the actual water-bottle employed, in order to arrive at certain results.

I have, therefore, been obliged provisionally to discontinue the experiments just referred to. They will, at any rate, give some idea of how far Pettersson's insulated water-bottle of our pattern can be considered trustworthy for measuring the temperature of the sea. They will also give some notion of the manner in which the temperature of the surrounding water influences that of the water-bottle.

If the various curves are drawn for the changes of temperature caused in this way, according to the above experiments, it must strike the observer

how all of them seem to belong to the same order, and can be calculated with tolerable accuracy by the same quadratic equation:

$$\Delta_t = d\,(\alpha h + \beta h^2)$$

where Δ_t is the change of temperature in the water-bottle produced after a certain number of minutes h, by the difference d between the temperatures inside and outside the same.

If the conditions were as simple in the sea as in these experiments, *i.e.* if the difference between the temperatures inside and outside the water-bottle were invariably the same in all the water-layers through which it was hauled up, it would then be comparatively easy to calculate, with a considerable degree of accuracy, the decrease or increase in the temperature of the water-bottle hauled up from any depth, provided that the necessary formula was once determined by careful experiments. But since the temperatures of the sea change continuously with the depths, the calculation as mentioned above becomes considerably more complicated. Although theoretically it might be possible to calculate the change of temperature also from greater depths, our temperature-readings, taken simultaneously by Pettersson's water-bottle and by the reversing thermometers (see later), prove that the former cannot be considered very trustworthy for depths exceeding 1000 metres.

We now turn to the series of temperatures taken with Pettersson's water-bottle during our expedition. In most cases, a Negretti and Zambra reversing thermometer was sent down along with the water-bottle, and by means of the temperatures taken simultaneously in this way, we can determine, with a certain degree of accuracy, the loss of heat which the water-sample in the bottle has suffered by being hauled up through the colder water-strata. By taking the means of the many determinations thus obtained, we arrive at a fairly high degree of accuracy, and are thus enabled to calculate the rate of the temperature-change caused inside the water-bottle by the temperatures of the upper water-strata of the sea. Trying to make these calculations by the formula and in the manner indicated above, I found it to be a long and complicated work, which would not give proportionally accurate results. As, however, the temperature-changes in question are comparatively small, down to certain depths, and as in our series of temperatures we could not, in any case, arrive at such a high degree of accuracy for the greater depths, by this

method, as was obtained by the reversing thermometers, I think we can calculate the temperature-changes in Pettersson's water-bottle for the lesser depths in a much simpler way, without risking errors of more than one or two hundredths of a degree, by supposing that the changes of temperature — when the temperature-differences are small — increase along a straight line instead of a curve.

In the case of our series of temperatures, the vertical distribution of the temperatures also helps to make this supposition more correct, as it causes the curve for the temperature-changes to approach a straight line. The greatest temperature-differences are near the surface, in the upper 200 or 100 metres, which a water-sample reaches last when it is hauled up from any depth. If, *e.g.* a water-sample which is hauled up from 400 m. were at once exposed to the same temperature-difference as a water-sample which is hauled up from 200 m., the change in its temperature should probably be very nearly 6 times that of the latter when they reached the surface, not considering the diminution of temperature owing to the expansion of the water, and provided that they are hauled up with the same velocity. As it is, however, the water-sample from 400 m. will not be exposed to any considerable temperature-difference — only a few tenths of a degree — before it approaches 200 m., after which it will get most of the temperature-difference to which it is exposed. The result is that its change of temperature will be very little more than double that of the sample from 200 m.

If we suppose that the time required to haul the water-bottle up through a distance of 100 metres is the same in all depths, and α is the amount by which the temperature of the water-sample in the bottle is altered (decreased or increased) by being hauled through 100 metres of water with a temperature one degree centigrade higher or lower, then according to the supposition we have started with, the loss of temperature should be $2\,\alpha$ by being hauled through 200 m. of water with one degree centigrade lower temperature, whilst the loss will be α if the difference of temperature is only half a degree, etc.

If α is determined by experiment, δ is the average of the differences between the temperature of the water-sample, and those of the water-layers through which the bottle has to pass, m is the depth in metres divided by 100, Δ_t is the total increase or decrease in the temperature of the water-

sample by its being hauled up from the depth m . 100 metres. Then Δ_t for any depth is:

$$\Delta_t = m \,.\, \delta \,.\, \alpha$$

When trying to find α and Δ_t for our series of temperatures, in order to be able to correct the temperature-readings obtained by Pettersson's water-bottle, there is the difficulty that the time required for hauling up from the various depths differs very much in the various cases. This is mostly owing to the fact that various kinds of line were used at different times. To a smaller extent, it may also depend upon the temperature of the air, as the hauling will generally be somewhat retarded in very low temperatures by various difficulties, such as freezing of the water on the line, etc.

In April and May, 1894, we used a hempen line which was very heavy in the water; the hauling up was therefore slow work, and the water-bottle spent a comparatively long time on its way from any depth to the surface. The result obtained at that time is therefore not very satisfactory as regards the insulation of the water-bottle. In June, 1894, however, we had made a sounding-line of steel-wire, which was then used for taking the water-temperatures. As this line ran easily through the water, hauling became very much quicker work than before, and the water-bottle spent a very much shorter time in coming from any given depth to the surface. The result may be seen at once on comparing the temperatures registered by the reversing thermometers, and by the thermometer of the water-bottle, the differences being very much less than they were in April and May, and seeming to change very regularly with the depth.

By averaging all the observations taken on June 25th and 26th, 1894, simultaneously with Negretti and Zambra's reversing thermometer No. 75682, and with Pettersson's insulated water-bottle (and thermometer R. Grave) from depths between 275 m. and 400 m. (see the tables of temperatures for those dates), I find that the total diminution of temperature of the water-sample when hauled up from 325 metres — where the temperature averaged about + 0·40° C. (June 26th, 1894) — should have been = 0·063° C.

From the table, p. 6, it is seen that the temperature of a water-sample is diminished 0·013° C. by the expansion of the water, when hauled up from 325 m. There remains in consequence 0·050° C., which should be the diminution of temperature owing to the influence of the colder water-strata above

325 m. The influence of the air-temperature can be left out of consideration, as it was, during these days, between zero and —1·5° C., or very nearly the same as that of the water-samples.

The differences, δ, between the temperature at 325 m. and those of the water-strata between 325 m. and the surface, average about 1·015° C., and we then have:

$$\alpha = \frac{\Delta_t}{m \,.\, \delta} = \frac{0{\cdot}05}{3{\cdot}25 \times 1{\cdot}015} = 0{\cdot}015\,^{0}\text{ C.}$$

By the aid of this coefficient, $\alpha = 0{\cdot}015\,^{0}$ C., one can now calculate the probable increase or decrease caused in the temperature of a water-sample from any given depth on its way to the surface, provided that the temperatures of the water-layers above are known. By adding the correction for pressure (table p. 6) one finds the correction which should be applied to the temperature-readings of the water-bottle, in order to give the exact temperature of the water *in situ*.

The corrections found in this way may be fairly trustworthy for lesser depths, as long as the intervals of time required to haul the water-bottle up through every hundred metres, are fairly uniform. But in greater depths, these periods become, as a rule, longer, owing to the fact that the hauling becomes heavier. As an illustration it may be mentioned that on June 25th and 27th, 1894, the hauling up took:

from	200 m.	2	minutes,	15	seconds.
„	450 „	8	—	—	
„	500 „	10	—	—	
„	600 „	13	—	—	
„	700 „	16	—	—	
„	1200 „	35	—	—	

This circumstance makes the matter more complicated[1], and as there will certainly always be irregular variations in the length of time necessary to haul the water-bottle up a certain distance, as long as the line is not worked by machinery, the corrections found for greater depths cannot be

[1] It should be remembered that on the other hand an increased velocity of the water-bottle through the surrounding water increases the thermal effect of the latter upon the water in the bottle, see p. 10.

trustworthy, even if the formula used for the calculation were more accurate than the one above.

Making certain allowances for the variations which have probably occurred in the intervals of time required for hauling up from the different depths, I have calculated the decrease or increase of temperature which the water-samples have undergone by being hauled up through the colder or warmer water-strata from the various depths down to 1000 metres. For greater depths, the calculation is too uncertain to be of any value. By adding the changes thus found to the diminution of temperature produced by the expansion of the water (see p. 6), I find the total corrections, by which the temperatures taken by the water-bottle in June, 1894, have to be reduced, in order to give the temperatures of the water *in situ* (see the second column of the following table). The first column gives the corresponding depths, and the third column gives, for the sake of comparison, the corrections for the same depths found by direct observation, by averaging the differences between the indications of the N. & Z. reversing thermometers, and those of the water-bottle.

Corrections for the temperature-readings taken by Pettersson's water-bottle, June and August, 1894.

Depth.	Calculated corrections.	Observed corrections in June 1894.
150 m.	+ 0·01° C.	+ 0·01° C.
200 „	+ 0·02 „	+ 0·02 „
250 „	+ 0·04 „	+ 0·03 „
300 „	+ 0·06 „	+ 0·06 „
400 „	+ 0·07 „	+ 0·09 „
500 „	+ 0·07 „	+ 0·07 „
600 „	+ 0·05 „	+ 0·03 „
700 „	+ 0·04 „	+ 0·00 „
800 „	+ 0·03 „	+ 0·02 „
900 „	+ 0·02 „	
1000 „	+ 0·00 „	— 0·02 „

It will be seen that the corrections found by direct observations agree fairly well with the calculated ones down to depths of 1000 m., the disagreements not exceeding 0·02° C. except in the case of 700 m., where there is evidently

some error in the observation. Below 1000 m. the disagreements are much larger, which may, to some extent, be owing to irregularities in the length of time required for hauling up, which for the greater depths was often very slow work. The chief cause of these disagreements between the observed and the calculated corrections is, however, probably that the formula used for the calculation does not hold good for such great changes of temperature; we supposed that they were represented by a straight line instead of a curve. The disagreements between the observed and calculated corrections at 400 m. have probably the same cause. It is peculiar that the differences Δ_t, between the indications of the reversing thermometers and the thermometer of the water-bottle, were less for 300 metres than for 375 to 425 metres on June 26th, 1894, although the product $m\,\delta$ of the depth (m) and the average difference (δ) between the temperatures inside and outside the water-bottle, on its way to the surface, is larger for the former depth than for the latter ones.

For 300 metres $m\,\delta$ was on that date about 3·8.

„ 400 metres $m\,\delta = 3{\cdot}5$,

„ 500 metres $m\,\delta =$ about 3·1.

Δ_t was nevertheless on that date

for 300 metres = 0·05 ° C. — 0·01 ° C. (correction for pressure, see p. 6)

„ 400 metres = about 0·09 ° C. or 0·08 ° C. — 0·02 ° C.

For 500 m. it is about the same (*i. e.* for 450 m. the observations give $\Delta_t = 0{\cdot}06$ ° C. — 0·02 ° C. and for 500 m. $\Delta_t = 0{\cdot}10$ ° C. — 0·02 ° C.).

If we would take the necessary trouble to find out the correct formulæ (quadratic or cubic equations), and the correct coefficients, and also take the trouble to use them, and if, moreover, the length of time spent by the water-bottle on passing through every hundred metres of its way to the surface, were carefully noted, I think the corrections for the loss or gain of heat during the hauling up could be calculated with a tolerably high degree of accuracy for temperatures taken by the water-bottle from almost any depth; and provided that due consideration was also given to the influence of the air-temperature, the heat absorbed by the expansion of the water, etc., we could obtain fairly accurate temperatures by this water-bottle even from greater depths, which in any case might be useful in verifying the indications of the reversing thermometers. The accuracy of the temperatures obtained

would naturally be increased if the insulation of Pettersson's water-bottle were made still more efficient.

By comparing the temperatures taken by the water-bottle in April and May, 1894, with those taken by the Negretti and Zambra reversing thermometers at the same time, it may be seen that the differences between them are very much greater than those found for June, 1894. As before mentioned, this is probably to a great extent caused by a hempen-line being used instead of a line of steel-wire. The lower temperature of the air in April and May has probably also, to some extent, increased these differences between the readings, as it may have lowered the readings of the water-bottle thermometer, as mentioned on p. 10.

On drawing diagrammatic curves of the temperature-readings of the reversing thermometer, and those of the water-bottle taken in April (14th—15th and 23rd—26th) and May (22nd—26th) 1894, we find that, apart from lesser irregularities evidently caused by errors of observation [1], these curves follow each other fairly well down to 150 metres, where they gradually begin to part, their divergence going on until between 400 and 500 metres. Then they again begin to approach each other slowly, until they meet and cross at about 1100 or 1200 metres. Below this depth, the water-bottle gives higher temperatures than the reversing thermometer, the difference between them increasing with the depth.

By elimination of the evident irregularities, and by using the same method as above, for the series of temperatures for June, 1894, I find α for April $= 0{\cdot}06^{\circ}$ C. and α for May $= 0{\cdot}04^{\circ}$ C. The corrections with which the temperatures of the water-bottle obtained for the various depths have to be reduced, will be found by calculation to be the following for April and May:

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[1] These errors of observation are especially prominent in the beginning, in April, when I had not acquired facility in reading accurately the reversing thermometers; but later on, especially after June, 1894, I read them off with a lens and by careful levelling of the eye. The curves of May, 1894, exhibit an improvement compared with those of April, and there appears to be only one great irregularity in the temperature-curve of the water-bottle, viz. at 500 metres, which may have been caused by some accidental stop in the hauling up.

	Corrections for April, 1894.		*Corrections for May, 1894.*	
	found by calculation.	found by observation.	found by calculation.	found by averaging observations.
150 m.	+ 0·05° C.	+ 0·05° C.	+ 0·02° C.	
200 „	+ 0·13 „	+ 0·19 „	+ 0·09 „	+ 0·10° C.
300 „	+ 0·21 „	+ 0·24 „	+ 0·14 „	
400 „	+ 0·23 „	+ 0·21 „	+ 0·18 „	+ 0·18 „
500 „	+ 0·23 „	+ 0·21 „	+ 0·18 „	+ 0·18 „
600 „	+ 0·18 „	+ 0·23 „	+ 0·14 „	+ 0·16 „
700 „	+ 0·14 „		+ 0·11 „	+ 0·13 „
800 „	+ 0·10 „	+ 0·07 „	+ 0·09 „	+ 0·10 „
900 „			+ 0·07 „	+ 0·10 „
1000 „	+ 0·06 „		+ 0·05 „	+ 0·03 „

The lower temperature-readings of the thermometer of the water-bottle in April, compared with May, may perhaps to some extent be accounted for by the lower temperature of the air in April, which was between — 17° C. and — 20° C., whilst in May the air-temperature was mostly between — 5° C. and — 8° C., and in June about zero. As is mentioned at some length pp. 9—10, there is a liability to get too low temperature-readings by the water-bottle on cold days, and the water-bottle temperatures of April may in this manner have become some hundredths of a degree too low, perhaps 0·03° or 0·04° C., whilst the readings of May may be 0·01° C. too low. In June this has not been the case to any appreciable degree, as the temperature of the air was practically the same as that of the water-sample.

In the calculation of the corrections, it has been supposed that the time required for hauling the water-bottle up through every 100 metres has been the same in all depths, but in spite of this, it may be seen that the calculated corrections agree fairly well with the corrections in the third and fifth columns of the table, found directly from the observations, by averaging the differences between the temperature-readings of the reversing thermometers, and those taken by the water-bottle. The reason is evidently that the hauling was such heavy work that when the temperatures were taken from the greater depths, more men were required for it than from the lesser depths. The velocity with which the water-bottle came up was therefore much more uniform than it was later in June, when only a few men were employed for hauling

up the sounding-line of steel-wire, even from considerable depths, and the hauling was consequently much more retarded with the increase of depth.

For the series of temperatures taken by the water-bottle on August 13th—17th, 1894, we may assume the corrections to be nearly the same as they were in June of the same year, for they were taken in quite a similar manner, and a sounding-line of steel-wire was used. Nevertheless the differences between the temperature-readings of the water-bottle and those of the reversing thermometer, which follow each other with extreme regularity, are smaller here than they were in June. This must be owing to variations in the corrections of the thermometers, perhaps to some extent caused by less elevation of the zero of the reversing thermometer (see later). It cannot be caused by the temperature of the air, as this was very nearly the same as it was in June.

The series of water-temperatures for October and November, 1894, exhibit much more irregularity in the differences between the temperature-readings of the water-bottle and those of the reversing thermometers. This is owing to the low temperature of the air at that time, which was about — 30° C. both in October and November, and caused many difficulties in using the water-bottle. If it was simply hauled up and left hanging in the air while the thermometer was inserted and the temperatures were read off, the water in the outer jacket of the bottle would begin to freeze, the stop-cock would be closed by ice, etc. When the water-bottle came to the surface, it was therefore necessary to leave it hanging in the water, with the upper lid just above the surface, while the thermometer was inserted and allowed the necessary time for registering the temperature. The water-bottle was then quickly lifted up, and the temperature read off at once by the aid of a lens and a lantern; and the water-sample was taken before any water inside the water-bottle had time to freeze. After this the instrument was put in hot water, in order to thaw away all ice formed on it. And when it was sufficiently heated, it was sent down quickly to the desired depth from which a new water-sample was to be taken. If this was not done, the result would be, that the water-bottle would take the temperature of the air, and when the bottle was thus sent down into the sea, ice would be formed round it at once, preventing it from working properly, and it might even happen that it would come up open as it was sent down.

It will be understood that under these circumstances the temperature-readings obtained by the insulated water-bottle may easily be somewhat lowered, as the loss of temperature of the water in the bottle will be larger than usual, exposed as it is for a much longer time to the cooling influence of the water-layer at the surface. The result of this influence may be clearly seen in the water-temperatures of October and November, 1894, when there was much irregularity in the differences between the temperature-readings of the water-bottle and those of the reversing thermometers; and these disagreements were especially appreciable in the depths where the temperatures differ much from that of the surface. In the lesser depths, about 150 m., where the temperature is very nearly the same as that of the surface, the difference is practically what may be expected (see later).

In connection with what is here said about the insulating properties of Pettersson's water-bottle, it may be of interest, for comparison, to give a series of temperatures taken simultaneously by this water-bottle and a N. & Z. reversing thermometer down to 940 m. at Storeggen, off the Norwegian west coast, in 63° 38·3′ N. Lat. and 5° 31¼′ E. Long. The series was taken on August 4th, 1897, by Capt. S. Müller, of the Norwegian navy, on board the sounding ship 'Hansteen' of our Coast Survey, and was kindly placed at my disposal by Dr. Johan Hjort.

Depth.	Temperatures taken by Pettersson's water-bottle and Fr. Müller thermom.	Temp. taken by N. & Z. therm.	Difference by which the *t.* of the water-bottle is higher than N. & Z, when reduced by the correction for pressure.
0 m.	12·85° C.		
20 „	9·91		
40 „	9·6		
60 „	9·2		
80 „	9·0		
100 „	8·7		
150 „	8·35		
200 „	8·05		
250 „	7·5		
300 „	7·45		
350 „	7·1	7·0° C.	0·11° C.
400 „	6·95	6·8	0·17
450 „	6·65	6·5	0·17
500 „	6·3	6·1	0·22
550 „	6·0	5·9	0·12
575 „	5·1	4·9	0·22
600 „	3·6	3·4	0·22
625 „	3·1	2·9	0·22
650 „	1·1	— 0·7	0·42
700 „	0·5	— 0·7	1·23
800 „	0·4	— 0·8	1·23
900 „	0·3	— 0·9	1·23
940 „	— 0·35	— 1·0	0·68

THE THERMOMETERS AND THEIR ERRORS.

In the following, I shall try to describe as accurately as possible the various thermometers used in the oceanic researches of the expedition, as well as the manner in which the errors of these instruments have been determined. The reader will thus have the material necessary to judge for himself how far the results are to be trusted.

In trying to determine the zero-correction of the thermometers during the expedition, we met with the difficulty that the snow as well as the ice on the floes round the 'Fram' always contained some salt. This was partly caused by the wind, which would carry along to any place the salt or frozen brine formed on the surface of the newly frozen ice of the water-lanes. The snow in the crow's nest, 100 feet above the ice, was even made saline in this way. When the snow lay for some time on the floes, it would soon absorb a little salt from the brine on the top of the ice underneath it, and thus it also became saline.

Capt. Scott-Hansen therefore chiefly used hoar-frost for testing the zero of the thermometers. This hoar-frost was formed inside the Fram, by condensation of the moisture during the winter. It was generally collected from the ceiling in the chart-room, but even there it occasionally contained traces of salt, as could be proved by nitrate of silver. This salt had evidently found its way in with the drifting snow-dust on very windy days.

Küchler No. I.

This thermometer, with two similar ones, was ordered by Mr. Hercules Tornøe, from Alexander Küchler & Söhne in Ilmenau, for his apparatus for determining the electric resistance of the sea-water. As it has no other mark than an "I" written with diamond, I have called this instrument Küchler No. I.

It is made of "Jena Normal-Glas, 16 III", and is 35 cm. long. The bulb is 3 cm. long, with a diameter of about 4 mm. The diameter of the stem is about 5·5 mm. The back of the stem is enamelled white. The scale, 29 cm. long, is engraved on the stem, and ranges from -5^{0} C. to $+30^{0}$ C. The scale is divided into tenths of degrees, the distance between each division-mark being 0·8 mm. (the length of one degree = 8 mm) so that a hundredth of a degree can with comparative ease be read off by estimation.

Mr. Tornøe determined the errors of graduation, etc. of this instrument very accurately before our departure (in May, 1893) by comparing it with his own standard thermometer [1]. He found the corrections given in the second column of the table on next page. By these corrections the temperature-readings of the instrument, between zero and + 20 ° C., are reduced to the indications of the *hydrogen thermometer*. The corresponding corrections for reducing the readings to the indications of the *mercurial thermometer* of "Jena Normal-Glass", or "verre dur", are given in the third column of the table [2].

During the expedition, the zero-corrections of the instrument were determined by Capt. Scott-Hansen to be:

		Zero-correction of Küchler No. I.
October	18, 1893	— 0·04 ° C.
December	19, 1893 . . .	± 0·00 „ [3]
—	20, 1893	— 0·05 „
February	1, 1894	— 0·05 „
—	1, 1894	— 0·05 „
—	1, 1894	— 0·05 „
—	27, 1894	— 0·05 „
April	12, 1894	— 0·04 „

Scott-Hansen makes the remark in the journal that the determination on February 27th was made in hoar-frost which contained no salt, whilst in the hoar-frost used on February 1st, the presence of just a suspicion of salt could be proved by adding nitrate of silver.

In March, 1898, Prof. Mohn tested the zero of the thermometer, and found it to be 0·07 ° C. too high (the correction = — 0·07 ° C.).

In July, 1898, Prof. Sophus Torup and I made several series of careful comparisons between this instrument and the standard thermometer (Tonnelot) of the Physiological Laboratory of the Christiania University [4]. The zero was tested in melting ice. The corrections found for reduction to the temperatures of the mercurial thermometer, of "Jena Normal-Glas" or "verre

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[1] This thermometer is from Tonnelot, Paris ("en verre dur" No. 4519), and has been tested at the Bureau International de Poids et Mesures. It is divided into fifths of degrees.

[2] The latter corrections are found by the table given, according to the determinations of M. Chappuis, in: Guillaume, 'Traité pratique de la Thermométrie de Précision', Paris, 1889, p. 332.

[3] The snow used on this occasion has probably not been quite pure.

[4] This thermometer, Tonnelot No. 4867, is made of "verre dur", and is divided into tenths of degrees. It has been tested at the Bureau International des Poids et Mesures.

dur", are given in the fourth column of the table. The two corrections at 8·4° C. and 11·5° C. are the results of 6 independent comparisons with Tonnelot No. 4867, taken at temperatures between 8·10° C. and 8·90° C., and 20 comparisons between 11·18° C. and 11·92° C.

Thermometer Küchler No. I.

	May, 1893. Corrections for reducing to indications of the *hydrogen thermometer.*	*May, 1893.* Corrections for reducing to indications of the *mercurial thermometer.*	*Spring, 1894.* Corrections for reducing to indications of the *mercurial thermometer.*	*July, 1898.* Corrections for reducing to indications of the *mercurial thermometer.*
0	0·00° C.	0·00 ° C.	— 0·05° C.	— 0·09° C.
1	— 0·02 „	— 0·014 „	— 0·06 „	
2	— 0·04 „	— 0·028 „	— 0·08 „	
3	— 0·05 „	— 0·032 „	— 0·08 „	
4	— 0·07 „	— 0·047 „	— 0·10 „	
5	— 0·08 „	— 0·052 „	— 0·10 „	
6	— 0·07 „	— 0·037 „	— 0·09 „	
7	— 0·06 „	— 0·022 „	— 0·07 „	
8	— 0·04 „	+ 0·003 „	— 0·05 „	
8·4		+ 0·013 „	— 0·04 „	— 0·074 „
9	— 0·02 „	+ 0·027 „	— 0·02 „	
10	+ 0·01 „	+ 0·062 „	+ 0·01 „	
11	+ 0·02 „	+ 0·076 „	+ 0·03 „	— 0·026 „
11·5		+ 0·068 „	+ 0·02 „	— 0·030 „
12	— 0·00 „	+ 0·060 „	+ 0·01 „	— 0·034 „
13	— 0·02 „	+ 0·043 „	— 0·01 „	
14	— 0·01 „	+ 0·057 „	+ 0·01 „	
15	+ 0·01 „	+ 0·08 „	+ 0·03 „	
16	+ 0·01 „	+ 0·083 „	+ 0·03 „	
17	— 0·01 „	+ 0·066 „	+ 0·02 „	
18	— 0·03 „	+ 0·049 „	0·00 „	
19	— 0·04 „	+ 0·042 „	— 0·01 „	
20	— 0·05 „	+ 0·035 „	— 0·01 „	

For determinations of the zero-corrections, we used the ordinary fresh-water ice of Christiania, which is unusually pure. The zero-corrections were taken three times (July 2nd, 4th and 11th, 1898) and were found to be — 0·09 ° C., — 0·09° C. and — 0·075 ° C., the mean of which is — 0·085 ° C. On December 21st, 1898, I determined the zero-correction again in pure snow, and found it to be — 0·095 ° C.

On comparing the corrections of 1898 with those of 1893, it thus appears that the zero during that time has risen from 0·0 to + 0·09 ° C. At 8·4 ° C. the correction has changed from + 0·013 to — 0·074° C. (an alteration of 0·087 °), and at 11·5° C. from + 0·068° C. to — 0·030° C. (an alteration of 0·098 °). This is hardly greater variation than may lie within the limit of errors of observation.

By drawing the probable curve for the alteration of the zero-correction, we can find with a fair degree of accuracy the probable zero-correction for any intervening date, and hence find the probable correction for any temperature between 0° and 20 ° C.

Küchler Nos. II and III.

These thermometers were exactly similar to Küchler No. I. But as one of them (No. III) was broken by an accident in a heavy sea in August, 1893, and the other was broken in the spring of 1894, they were but little used during the expedition.

Mr. Tornøe determined their corrections for reducing the temperature-readings to the indications of the hydrogen thermometer, in May, 1893, and they will be found in the following table for both thermometers.

	Corrections for Küchler No. II.	*Corrections for Küchler No. III.*
0 ° C.	0·00	0·00
1 „	— 0·01	0·00
2 „	— 0·02	0·00
3 „	— 0·03	0·00
4 „	— 0·04	0·00
5 „	— 0·04	0·00
6 „	— 0·04	+ 0·01
7 „	— 0·03	+ 0·01
8 „	— 0·02	+ 0·02

	Corrections for Küchler No. II.	*Corrections for Küchler No. III.*
9 „	— 0·01	+ 0·03
10 „	+ 0·01	+ 0·05
11 „	+ 0·01	+ 0·05
12 „	0·00	+ 0·03
13 „	0·00	+ 0·01
14 „	+ 0·01	+ 0·01
15 „	+ 0·04	+ 0·03
16 „	+ 0·03	+ 0·04
17 „	0·00	+ 0·02
18 „	— 0·04	+ 0·02
19 „	— 0·06	+ 0·02
20 „	— 0·07	+ 0·03

Frz. Müller No. 7.

This thermometer had been ordered by Prof. Otto Pettersson for his insulated water-bottle, and was much used during the first years of the expedition. It is made by "Dr. H. Geissler Nachfolger Frz. Müller" in Bonn, of "Jena Normal Glass 16 III" (with a red line along the tube and bulb). The instrument is 31 cm. long. The bulb is 22 mm. long, with a diameter of 6·8 mm. The stem is very narrow, its outer diameter being hardly more than 1·8 mm., and this makes the thermometer somewhat sluggish; it often required two minutes to reach its permanent indication. The thermometer is protected by an outer glass-tube 9 mm. in diameter. The graduation is unfortunately not engraved on the stem , but is marked on a scale of white opal glass fixed inside the outer tube. The scale, ranging from — 3·5 ° C. to + 12 ° C., is 22·8 cm. long. It is divided into twentieths of degrees, (0·05 ° C.), and the distance between the division marks is 0·7 mm. The hundredth part of a degree can thus be read off quite easily by estimation. During the latter part of the expedition, the scale had become loosened, and had changed its position to the extent of about 0·25 ° C. It remained thus during July, 1898, and this is the reason that the corrections found then differ greatly from the others. During the expedition, the thermometer was not used after the scale had altered its position inside the outer tube.

By numerous comparisons with the standard thermometer ("en verre dur" of *Tonnelot*) of the Physiological Institute, Christiania, taken July 2nd, 9th, and 11th, 1898, Prof. Torup and I have found the corrections given in the fourth column of the following table, for temperatures ranging from —2° C. to +12° C., to be applied for reducing the readings to *the indications of the mercurial thermometer* ("en verre dur").

Frz. Müller No. 7.

Corrections for reducing the readings to the indications of the mercurial thermometer of 'verre dur'.

Temperature-reading.	Corrections February 1894.	Corrections April 1894.	Corrections July 1898.	Corrections December 1898.
—2 ° C.	—0·05° C.	—0·06° C.	+0·21° C.	
—1·5 „	—0·05 „	—0·06 „	+0·21 „	
—1·0 „	—0·04 „	—0·05 „	+0·22 „	
—0·5 „	—0·04 „	—0·05 „	+0·22 „	
0·0 „	—0·04 „	—0·05 „	+0·22 „	—00·7° C.
+0·5 „	—0·05 „	—0·06 „	+0·21 „	
1 „	—0·04 „	—0·05 „	+0·22 „	
1·5 „	—0·04 „	—0·05 „	+0·22 „	
2 „	—0·03 „	—0·04 „	+0·23 „	
3 „	—0·02 „	—0·03 „	+0·24 „	
4 „	—0 02 „	—0·03 „	+0·24 „	
5 „	—0·03 „	—0·04 „	+0·23 „	
6 „	—0·03 „	—0·04 „	+0·23 „	
7 „	—0·02 „	—0·03 „	+0·24 „	—0·06[1] „
8 „	—0·01 „	—0·02 „	+0·25 „	
9 „	—0·01 „	—0·02 „	+0·25 „	
10 „	0·00 „	—0·01 „	+0·26 „	
11 „	+0·01 „	0·00 „	+0·27 „	
12 „	+0·01 „	0·00 „	+0·27 „	—0·01[1] „

[1] These determinations were not made very carefully, and have therefore no pretence to a high degree of accuracy.

On February 1st, 1894, Capt. Scott-Hansen found the zero-correction of this instrument, by three independent determinations, to be — 0·035° C. (exactly the same every time). He used, however, hoar-frost collected inside the 'Fram' for the determination (as the snow on the floes contained too much salt), and he says that this was not absolutely destitute of salt. The specific gravity of the melted water was found, by a hydrometer of Küchler, to be 1·0013 at 8·0° C. (corrected temperature). This specific gravity reduced to $\frac{17{\cdot}5^{0}\text{ C.}}{17{\cdot}5^{0}\text{ C.}}$ would be about 1·0003, corresponding to a salinity of about 0·4 ‰, which would be able to lower the freezing-point of the water about 0·02° C. at most. The correction of the hydrometer was not, however, determined, and as it has now gone with Captain Sverdrup on his new expedition in the Fram, there is no possibility of examining it at present. But judging from similar hydrometers received from Küchler simultaneously (in 1876) with the one here employed, this has probably indicated somewhat too high. On the other hydrometers there has generally been a correction of about — 0·0002 or — 0·0003[1] and it is possible that this instrument had a similar correction, and thus the amount of salt in the hoar-frost has been so insignificant, that it has really been of no importance; its existence could just be proved by adding nitrate of silver to the melted water. When, therefore, we say that the zero-correction of Müller No. 7 has been — 0·04 on February 1st, 1894, we cannot be more than, say 0·005° C. from absolute accuracy; and according to this, we get the corrections given in the second column of the table for the temperatures between — 2° and + 12° C. for that date.

On April 23rd, 1894, this thermometer was compared with Küchler No. I, which was used as a standard thermometer. The comparisons were made by the following readings, taken at intervals (marked by horizontal lines in the table), in water which was thus given time to assume very nearly the temperature of the cabin.

During the last readings, the water appears to have acquired a permanent temperature, and the thermometer Müller No. 7 has reached its permanent indication, which is consequently 0·005° C. higher than Küchler No. I.

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[1] Cf. Hercules Tornøe: 'The Norwegian North-Atlantic Expedition 1876—1878. Chemistry,' p. 55.

Küchler I.	Müller No. 7.	*Δ*.
11·70° C. 11·73 „	11·80° C. 11·84 „	
11·80 „ 11·90 „	11·90 „ 11·96 „	
11·98 „ 11·98 „	11·99 „	0·01° C.
11·99 „ 11·99 „	11·995 „	0·005 „

According to the curve of the secular rise of the zero of Küchler No. I, drawn as mentioned on p. 30, its zero-correction should have been — 0·05° C. in April, 1894 (the same correction as that found by Scott-Hansen on February 27th, 1894), which indicates the amount by which the errors of this thermometer had changed between May, 1893, and April, 1894. The correction for the indication of 12° C. was + 0·06° C. in May, 1893, and should accordingly have been + 0·01° C. in April, 1894.

If, however, we go the other way, and say that the zero-correction in April, 1894, was 0·04° C. less than it was in July, 1898, and that the correction for 12° C. was — 0·034° C. in July, 1898, we find that the correction for the same indication should have been + 0·006° for that instrument, which differs 0·004° from the correction found in the other way. The mean between the two will be a correction of + 0·008° for 12° C. of Küchler No. I in April, 1894. *And this will again give a correction of + 0·003° C. for the same indication of Müller No. 7 in April, 1894.*

Starting from this correction, and dropping the third decimal, we shall get the series of corrections given in the third column of the table, p. 32, in April, 1894, which corrections differ 0·007° from those found for February, 1894. Considering the different ways by which we have arrived at these results, the agreement must be said to be satisfactory.

By replacing the scale of the instrument approximately in its original position, I found the zero-correction on December 21st and 22nd, 1898, to be — 0·07° C. which seems to indicate that the zero has changed very slowly

since 1894, as has been the case with the following thermometer of exactly the same description and make. I found at the same time, but by a not very careful examination, the correction for 7° C. to be —0·06 C., and for 12° C. it was —0·01° C.

Frz. Müller No. 6.

This thermometer was received simultaneously with Müller No. 7, and is of exactly the same description and quality. It is still in good condition.

By comparison with the standard thermometer of the Physiological Institute, Christiania, in July, 1898, Professor Torup and I found the corrections given in the fourth column of the following table.

Frz. Müller No. 6.

Corrections for reducing the readings to the indications of the mercurial thermometer of 'verre dur'.

Tempera-ture-reading	Corrections Summer 1894.	Corrections Summer 1895.	Corrections July 1898.	Corrections December 1898.
— 2·0	— 0·03	— 0·06	— 0·09	
— 1·5	— 0·03	— 0·06	— 0·09	
— 1·0	— 0·03	— 0·06	— 0·09	
— 0·5	— 0·02	— 0·05	— 0·08	
0·0	— 0·02	— 0·05	— 0·08	— 0·08
+ 0·5	— 0·02	— 0·05	— 0·08	
1·0	— 0·02	— 0·05	— 0·08	
1·5	— 0·02	— 0·05	— 0·08	
2	— 0·01	— 0·04	— 0·07	
3	0·00	— 0·03	— 0·06	
4	0 00	— 0·03	— 0·06	
5	0·00	— 0·03	— 0·06	
6	+ 0·01	— 0·02	— 0·05	
7	+ 0·02	— 0·01	— 0·04	
8	+ 0·02	— 0·01	— 0·04	
9	+ 0·03	0·00	— 0·03	
10	+ 0·03	0·00	— 0·03	
11	+ 0·05	+ 0·02	— 0·01	
12	+ 0·05	+ 0·02	— 0·01	— 0·01

On June 22nd and 28th, 1894, the following comparisons were made between this instrument and Müller No. 7.

	Müller No. 7.	Müller No. 6.	Difference.
June 28th, 1894	+ 6·50° C.	6·45° C.	0·05° C.
	+ 6·54 „	6·49 „	0·05 „
	+ 6·59 „	6·54 „	0·05 „
		Mean:	0·05° C.
June 22nd, 1894	9·66° C.	9·625° C.	0·035° C.
	9·85 „	9·80 „	0·05 „
	9·85 „	9·825 „	0·025 „
		Mean:	0037° C.

Hence Müller No. 6 indicated at about 6·5° C. on the average 0·05° C., and at 9·8° C., 0·037° C. lower than No. 7. Introducing the corrections found for these indications of the latter thermometer in the summer of 1894, we arrive at the following corrections for *Müller No. 6*:

Indication.	Correction.
at 6° C.	+ 0·01° C.
„ 7 „	+ 0·02 „
„ 10 „	+ 0·03 „

which differ 0·06° C., 0·06° C., and 0·06° C. from the errors of the same indications in July, 1898.

We arrive accordingly at the corrections for June, 1894, given in the second column of the table.

Taking it for granted that the error of this instrument has changed slowly and regularly, as is generally the case with thermometers of 'Jena Normal Glass', we get for the summer of 1895 the corrections given in the third column of the table. I think we can be certain that these corrections are, in any case, not more than ± 0·02° C. from the truth.

The zero-correction was examined December 21st and 22nd, 1898, in melting snow, and was found by several independent readings to be — 0·08° C., the correction for 12° C. being at the same time — 0·01° C.

Frz. Müller No. 4.

This thermometer, which is of exactly the same description as No. 7 and No. 6, was only used for three series of temperatures in the Barentz Sea in 1893. As its mercury column had some tendency to divide, it was not used later. Afterwards the stem was somehow broken just above the bulb, and thus

I have no correction for this instrument. But considering how small the errors of the sister thermometers, Nos. 7 and 6, have been, I think we may assume that the errors of this instrument have been something similar, and were at that time insignificant at the temperatures observed, viz. between $-1{\cdot}7^0$ C. and $+3{\cdot}93^0$ C.

Thermometer R. Grave.

This small thermometer is marked R. Grave, and is evidently an old instrument made by Mr. Grave in Stockholm. On the outer tube is written with diamond: *0 = 0,1 1878 &. §.*

It came with the Ekman's water-bottle which Professor Pettersson kindly ordered for me from Stockholm.

The thermometer is 23·9 cm. long, the cylindrical bulb is 2·2 cm. long, the outer diameter of the stem is 1·8 mm., and the diameter of the outer tube is 8 mm. There is a distance of 12·5 cm. from zero to the bulb, so it is well adapted for taking the temperatures in Pettersson's water-bottle. It has a paper scale, 9 cm. long, fixed on the stem, and ranging from $-5{\cdot}0^0$ C. to $+31{\cdot}0^0$ C. It is divided into fifths of degrees, one degree being about 2·5 mm. long ($^1/_5{}^0$ C. = 0·5 mm.), so that reliable readings can be made only with an accuracy of a few hundredths of a degree ($\pm 0{\cdot}02^0$ C.).

When this thermometer was tested on July 2nd, 1898, a small air-bubble was found in the mercury column, dividing it into two parts. By heating and shaking, the air-bubble was driven out, but this operation naturally caused a depression of the zero, and even a week later (July 9th and 11th) the zero was $0{\cdot}07^0$ C. lower than it must have been in 1894 according to numerous comparisons then made with Müller Nos. 7 and 6, and also with the Negretti & Zambra reversing thermometers. Its zero-correction on July 11th, 1898 was $-0{\cdot}15^0$ C. In December, 1898, the zero had evidently again acquired its old position. The zero-correction on December 21st and 22nd, 1898, was $-0{\cdot}22^0$ C. (average of 6 independent readings). On December 26th, it was $-0{\cdot}225^0$ C. (average of 2 readings).

By comparisons with the standard thermometer (Tonnelot),[1] Prof. Torup and I found, on July 4th, 9th, and 11th, 1898, the corrections given in the third

[1] Cf. footnote 1, p. 28.

column in the following table. On December 25th and 26th, 1898, I found the corrections given in the fourth column.

Thermometer R. Grave.

Corrections for reducing the readings to the indications of the mercurial thermometer of 'verre dur'.

Tempera-ture-reading	Corrections Summer 1894.	Corrections July 1898.	Corrections December 1898.
— 2	— 0·21	— 0·14	
— 1·5	— 0·21	— 0·14	
— 1·0	— 0·22	— 0·15	
— 0·5			
0·0	— 0·22	— 0·15	— 0·22
+ 0·5	— 0·22	— 0·15	
1·0	— 0·23	— 0·16	
1·5	— 0·23	— 0·16	
5	— 0·25	— 0·18	
6	— 0·25	— 0·18	
7	— 0·25	— 0·18	
8	— 0·27	— 0·20	— 0·27
9	— 0·27	— 0·20	
10	— 0·26	— 0·19	— 0·27
11	— 0·26	— 0·19	
12	— 0·27	— 0·20	— 0·26
13			— 0·28
14			— 0·29

The following comparisons between this thermometer and Müller No. 7, are recorded in my journal for 1894:

Date 1894.	Depth.	Müller No. 7 indication.	R. Grave indication.	Difference Grave indicating higher than M. No. 7.	Grave correction summer 1894.
April 26th[1]		12·10° C.	12·40° C.	0·30° C.	— 0·30° C.

[1] As these comparisons, with those of June 22nd immediately following, are so few, and were not very carefully made, they are not very trustworthy.

Date 1894.	Depth.	Müller No 7 indication.	R. Grave indication.	Difference Grave indicating higher than M. No. 7.	Grave correction summer 1894.
June 22nd		9·95 „	10·20 „	0·25 „	— 0·26 „
		10·11 „	10·32 „	0·21 „	— 0·22 „
				mean: 0·23° C.	— 0·24° C.
May 22nd[1]	0·3 m.	— 1·62° C.	— 1·55° C.	0·07° C.	
	10 „	— 1·62 „	— 1·45 „	0·17 „	
	20 „	— 1·64 „	— 1·44 „	0·20 „	
	40 „	— 1·65 „	— 1·45 „	0·20 „	
				mean: 0·16° C.	— 0·22° C.
June 22nd[2]	10 m.	— 1·52° C.	— 1·36° C.[3]	0·16° C.	
	20 „	— 1·50 „	— 1·36 „ [3]	0·14 „	
	30 „	— 1·50 „	— 1·36 „	0·14 „	
				mean: 0·15° C.	— 0·21° C.

On June 28th, 1894, the following comparisons between Müller No. 6 and R. Grave are recorded:

Müller No. 6.	Grave.	Difference Grave indicating higher than No. 6.	Correction for R. Grave June 1894.
6·14° C.	6·40° C.	0·26° C.	
6·20 „	6·44 „	0·24 „	
6·32 „	6·58 „	0·26 „	
6·35 „	6·61 „	0·26 „	
6·38 „	6·64 „	0·26 „	
		mean: 0·26° C.	— 0·25° C.

By introducing the corrections found for Müller Nos. 7 and 6 for the summer of 1894 (see pp. 32 and 35), we have arrived at the corrections for R. Grave given in the last column of the tables.

Upon comparing these corrections with those found in July, 1898, we see that they exceed the latter:

at	12·40° C.	by	0·10° C.
„	10·26 „	„	0·05 „
„	6·50 „	„	0·07 „
„	— 1·36 „	„	0·07 „
„	— 1·47 „	„	0·08 „
		mean:	0·07° C.

[1] These temperatures were taken simultaneously with Pettersson's insulating water-bottle in various depths.

[2] These are the mean temperatures of different observations taken June 22nd and 23rd.

The differences between the corrections found for 1894 and for July, 1898, average accordingly 0·07° C., and the former are greater than the latter. This agrees very well with the most careful comparisons of 1894, which are those at about 6·50° C., and those made with Pettersson's water-bottle at about —1·36° C. and —1·47° C.

Starting from this difference of 0·07° C., we find the corrections for R. Grave in the summer of 1894 to be those given in the second column of the table. These corrections agree well with those found in December, 1898, the differences being within the limit of the errors of observation. For zero and 8° C. there is no difference, and for 10° C. and 12° C. the differences are only +0·01° C. and —0·01° C. The instrument has therefore evidently very nearly the same corrections now, as it had in 1894, and this is only what may be expected, considering that the instrument was already old (at least 16 years) in 1894. That the corrections, found in July, 1898, differ, is owing to the depression of zero caused by the heating of the thermometer, as mentioned above.

Negretti and Zambra's reversing Deep-Sea Thermometers.

We had eight of these instruments, which were specially made to order for the expedition. They were marked with numbers from 75677 to 75684, and were all of exactly the same shape and size. Their length was 24·3 cm., and the diameter of the shield or outer protecting tube of glass was 16·5 mm.

Three of the thermometers, viz. 75677, 75678, and 75679, were divided into tenths of degrees centigrade (0·1° C.) and the other five, with numbers from 75680 to 75684, were divided into fifths of degrees centigrade (0·2° C.). The graduations and figures were marked on the stem.

One of the former, No. 75679, is before me. The scale, ranging from —4·5° to +6·3° C. is 9·6 cm. long, one degree measuring 8·9 mm., and each division (= 0·1° C.) 0·89 mm. The two other thermometers graduated in divisions of 0·1° C. were exactly similar. The indications of these instruments could be read off by the aid of a lens with an accuracy of 0·01° C. One had only to be very careful that the thermometer was in a vertical

position, and that the eye was exactly level with the top of the mercury[1]. This was important, as the stem on which the graduation was marked is comparatively thick, and there is thus some distance between the graduation marks and the mercury inside the stem. But the bore of the tubes of these thermometers was so small that the mercury very often failed to break off at the contraction at the neck of the bulb, when the instruments were turned over, the friction between the mercury and the glass-walls in the small bore probably counteracting the weight of the mercury, and preventing it from flowing down the tube[2]. The thermometers thus completely failed to register. This happened especially often at the lower temperatures — about and below zero — which prevail in the Polar Sea. These thermometers were therefore very little used.

The five thermometers divided into fifths of degrees were far better in this respect, the bore of the tube being somewhat larger; and the best of them seldom failed to register. Three of these thermometers returned from the expedition, and were in good condition. But they have gone out again with Captain Sverdrup on his new expedition in the 'Fram', and I am thus prevented from giving an exact description of them. They were of the same shape and size as the others (described above), only that the scale, being of the same length, had a wider range, so that the degrees, divided into fifths, were considerably shorter, about half the length. The indications of the thermometer could not, therefore, be easily read off closer than about 0·02° C. As, however, the mercury of these thermometers does not always break off exactly at the same point of the contraction of the stem, when they are turned over, there may be a little variation in the accuracy of their indications and we can, therefore, as a rule, hardly be certain that errors of as much as $\pm$ 0·05° may not occur in single readings. The corrections of these thermometers may also vary a little from one day to another, as the instruments do not appear to be made of the best kind of thermometer-glass.

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[1] During the polar summer when the horizon (of the ice-covered sea) could easily be seen, I ascertained that the eye was at the right level, by bringing the top of the mercury level with the horizon, and at the same time took care to keep it in the centre of the lens.

[2] I believe it would be an improvement in this respect to have the bore of the stem made cylindrical instead of flat, as the friction would then be reduced. In order to increase the weight of the mercury column, specially important at lower temperatures, it would be well to enlarge the receptacle at the end of the stem, or to enlarge the bore of the tube, as well as the bulb of the thermometer.

The temperatures taken with these thermometers were, however, when possible, checked by observations made simultaneously with Pettersson's insulated water-bottle and reliable thermometers (Müller No. 7, or Grave) at the same depths. Thus we are enabled to determine the corrections of the instruments almost every day that they have been used during the first years. Hence a higher degree of accuracy can be obtained. I think, therefore, I am fully justified in saying that the possible errors of the final water-temperatures found for the various depths of the North Polar Basin, very rarely exceed $\pm 0{\cdot}05^{0}$ C.; as a rule they are smaller, and with very few exceptions, *they can be guaranteed not to exceed* $\pm 0{\cdot}10^{0}$ *C.*

These reversing thermometers were tested by Professor Mohn at the Meteorological Institute of Christiania in May, 1893, just before our departure, as well as in March, 1898. He determined the zero-corrections to be:

Number of Thermometer.	Zero-correction May, 1893.	Zero-correction March, 1898.	
75677	$-0{\cdot}10^{0}$ C.	bulb broken[1]	
75678	0·00 „	− 0·23	
75679	0·00 „ (it does not always register).	bulb broken[1]	
75680	+ 0·07 „	− 0·00	(excellent).
75681	0·00 „	not returned	
75682	0·00 „	− 0·21	(very good).
75683	0·00 „	− 0·10	(not trustworthy, as more mercury easily slips down the tube after the turn over of the thermometer).
75684	0·00 „	not returned.	

This table will show that these instruments were fairly uniform, and their errors do not alter beyond comparatively narrow limits.

As the temperatures observed by us in the Polar Sea only vary between -1.8^{0} C., and $+1.0^{0}$ C., and the graduation, as well as the bore of the tube, proved to be very equal and regular in this part of the stem, the corrections found for zero or any of these temperatures will practically do for all water-temperatures observed with these instruments during the expedition.

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[1] The bulbs of these thermometers had evidently been broken, because the instruments had been kept in rooms with higher temperatures than the tubes would allow of, they being constructed for low temperatures only.

If the thermometers, for some time before they are read, are exposed to air which is very much colder than the water, the contraction of the broken-off column of mercury might easily cause a considerable error. As our thermometers, however, were always read as soon as they came out of the water, no significant error can have been caused in this way. The stem is insulated by air inside the shield, and the broken-off column of mercury will require some time to be much influenced by the temperature of the surrounding air. [1]

Only three of the Negretti and Zambra reversing thermometers, viz. No. 75680, 75682, and 75684, have been much used during the expedition, and I shall describe their corrections specially. All of them registered, as a rule, very well, and gave fairly uniform and accurate results. They were, as mentioned above (p. 40), graduated in divisions of 0.2° C., each division measuring about 0·8 mm.

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[1] The pressure of the water at the various depths has no appreciable effect upon the indications of these thermometers, so long as the shield is not broken. The coefficient of the cubic compression of a glass tube of additional pressure for every atmosphere is about 0·0000022. If the instrument is exposed to a pressure of 3000 metres of water, or about 300 atmospheres, its shield will consequently be compressed about 0·00066 of its volume; but the additional internal pressure of the tube exerted in this way can only be equal to 1 mm. of mercury, provided that the internal pressure is originally as much as an atmosphere, or 760 mm. Such a slight increase of the pressure will not be able to raise the indication of the thermometer appreciably. The case may, however, be somewhat more complicated by the plug or partition which confines the mercury surrounding the thermometer bulb, and which is cemented in a slight contraction of the shield around the neck of the bulb. By this plug, some air is also generally confined along with the mercury. The plug is hardly sufficiently yielding to accommodate itself at once to the increased pressure of this confined mercury and air caused by the compression of the shield. Thus the thermometer bulb may be exposed to a higher pressure than would otherwise be the case; but how much the pressure may thus be increased cannot be exactly calculated, as it will greatly depend on the elasticity of the plug, etc. It will, however, at any rate be so small that it cannot be of any importance in this connection, and can safely be left out of consideration.

I believe, however, that the compression of the shield is the cause of the mercury surrounding the thermometer bulb slipping down past the plug into the upper portion of the shield, as is the case in most instruments I have examined, after having been used for some time. This often goes so far, that hardly any mercury is left in the portion surrounding the bulb, a circumstance which is destructive to the sensitiveness of the thermometer. It happens perhaps in this way that the plug is compressed, especially in the greater depths, and then lets mercury past it when it is hauled up. I consider it would be an improvement to have holes in the plug allowing the mercury to flow slowly through in both directions; this would also have the advantage that when the thermometer was hauled up after having registered, the thermometer bulb would not be surrounded by mercury, and would thus be well insulated.

Negretti and Zambra No. 75682. (= NZ. 82.)

This instrument was very much used, and registered as a rule specially well. Its zero-corrections were, according to the determinations of Prof. Mohn:

in May, 1893, 0·00° C.
in March, 1898, — 0·21° C.

During the expedition many simultaneous observations were made at the same depths by this thermometer, and by Pettersson's insulated water-bottle, and the thermometers Müller No. 7 and R. Grave. In order to find the corrections of N. Z. 75682, I have collected the most trustworthy of these simultaneous observations from 1894 in the following table.

The *first column* of this table gives the date of the observation, the *second* the depth. The *third column* gives the name of the thermometer used in the water-bottle. In the *fourth column* is the temperature-reading of this thermometer, and in the *fifth* is this reading reduced by the error of the instrument (to the indications of the mercury thermometer of "verre dur") the *sixth column* gives the temperature of the water *in situ, i. e.* the corrected reading when reduced by the error caused by the passing of the water-bottle through the colder upper water-layers (cf. the tables pp. 21, 24). The simultaneous temperature-readings of N. Z. 75682 are found in the *seventh column*. By comparing these readings with the temperatures *in situ* obtained by the water-bottle, we find the corrections for 75682 given in the *eighth column*. Finally, the mean value of these corrections, partly found for depths between the surface and 120 m., and partly for lower depths, are given in the *ninth column*.

Date 1894	Depth	Temperature by Water-Bottle				N. Z. 75682			
		Therm.	Reading	Reading corrected by Error of Instr.	*t. in situ*	Reading	Difference of Read. from *t. in situ*	Correction of Instrument	
April 14	20 m.	Müll. 7	− 1·60° C.	− 1·66° C.	− 1·66° C.	− 1·53° C.	− 0·13° C.		
„ „	40 „	„	− 1·70 „	− 1·76 „	− 1·76 „	− 1·65 „	− 0·11 „		
„ „	60 „	„	− 1·85 „	− 1·91 „	− 1·91 „	− 1·67 „	− 0·24 „		
„ 15	80 „	„	− 1·75 „	− 1·81 „	− 1·81 „	− 1·61 „	− 0·20 „		− 0·16° C.
„ „	100 „	„	− 1·63 „	− 1·69 „	− 1·69 „	− 1·60 „	− 0·09 „		
„ „	120 „	„	− 1·55 „	− 1·61 „	− 1·60 „	− 1.44 „	− 0·16 „		
„ „	140 „	„	− 1·25 „	− 1·30 „	− 1·27 „	− 1·22 „	− 0·05 „		
„ „	160 „	„	− 0·95 „	− 1·00 „	− 0·94 „	− 0·80 „	− 0·14 „		
„ „	180 „	„	− 0·45 „	− 0·50 „	− 0·39 „	− 0·27 „	− 0·12 „		
„ „	200 „	„	− 0·38 „	− 0·43 „	− 0·30 „	− 0·04? „	− 0·26? „		
„ „	250 „	„	0·30 „	0·24 „	0·42 „	0·55 „	− 0·13 „		
„ „	250 „	„	0·16 „	0·11 „	0·29 „	0·12 „	(+ 0·17 „?)		− 0·126° C.
„ 23	250 „	„	− 0·10 „	− 0·15 „	0·03 „	0·09 „	− 0·06 „		
„ „	300 „	„	0·00 „	− 0·05 „	0·16 „	0·30 „	− 0·14 „		
„ „	300 „	„	0·00 „	− 0·05 „	0·16 „	0·32 „	− 0·16 „		
„ „	400 „	„	0·10 „	0·05 „	0·28 „	0·38 „	− 0·10 „		
„ „	500 „	„	0·10 „	0·05 „	0·28 „	0·375 „	− 0·10 „		
May 22	0·3 „	Müll. 7	− 1·62 „	− 1·68 „	− 1·68 „	− 1·60 „	− 0·08 „		
„ „	„ „	Grave	− 1·55 „	− 1·76 „	− 1·76 „	− 1·60 „	− 0·16 „		
„ „	10 „	Müll. 7	− 1·62 „	− 1·68 „	− 1·68 „	− 1·60 „	− 0·08 „		
„ „	„ „	Grave	− 1·45 „	− 1·66 “	− 1·66 „	− 1·60 „	− 0·06 „		
„ „	20 „	Müll. 7	− 1·64 „	− 1·70 „	− 1·70 „	− 1·60 „	− 0·10 „		
„ „	„ „	Grave	− 1·44 „	− 1·65 „	− 1·65 „	− 1·60 „	− 0·05 „		− 0·09° C.
„ „	40 „	Müll. 7	− 1·65 „	− 1·71 „	− 1·71 „	− 1·62 „	− 0·09 „		
„ „	„ „	Grave	− 1·45 „	− 1·66 „	− 1·66 „	− 1·62 „	− 0·04 „		
„ „	60 „	Müll. 7	− 1·71 „	− 1·77 „	− 1·77 „	− 1·65 „	− 0·12 „		
„ „	80 „	„	− 1·71 „	− 1·77 „	− 1·77 „	− 1·65 „	− 0·12 „		
„ „	100 „	„	− 1·58 „	− 1·64 „	− 1·63 „	− 1·52 „	− 0·11 „		
„ „	120 „	„	− 1·43 „	− 1·49 „	− 1·48 „	− 1·34 „	− 0·14 „		
„ „	160 „	„	− 1·12 „	− 1·17 „	− 1·14 „	− 1·10 „	− 0·04 „		
„ „	200 „	„	− 0·38 „	− 0·43 „	− 0·34 „	− 0·24 „	− 0·10 „		− 0.08° C.
„ „	240 „	„	− 0·16 „	− 0·21 „	− 0·10 „	− 0·02 „	− 0·08 „		
„ „	300 „	„	0·10 „	0·05 „	0·19 „	0·20 „	− 0·01 „		
„ „	400 „	„	0·18 „	0·13 „	0·31 „	0·40 „	− 0·09 „		
June 22	10 m.	Müll. 7	− 1·52 „	− 1·58 „	− 1·58 „	− 1·60 „	+ 0·02 „		
„ „	„ „	Grave	− 1·30 „	− 1·51 „	− 1·51 „	− 1·60 „	+ 0·09 „		
„ „	20 „	Müll. 7	− 1·50 „	− 1·56 „	− 1·56 „	− 1·56 „	0·00 „		
„ „	„ „	Grave	− 1·32 „	− 1·53 „	− 1·53 „	− 1·56 „	+ 0·03 „		
„ „	30 „	Müll. 7	− 1·50 „	− 1·56 „	− 1·56 „	− 1·60 „	+ 0·04 „		+ 0·02° C.
„ „	„ „	Grave	− 1·36 „	− 1·57 „	− 1·57 „	− 1·60 „	+ 0·03 „		
„ „	40 „	Müll. 7	− 1·50 „	− 1·56 „	− 1·56 „	− 1·62 „	+ 0·06 „		
„ „	50 „	Grave	− 1·51 „	− 1·72 „	− 1·72 „	− 1·64 „	− 0·08 „		
„ „	60 „	„	− 1·56 „	− 1·77 „	− 1·77 „	− 1·73 „	− 0·04 „		

Date 1894	Depth	Temperature by Water-Bottle				N. Z. 75682			
		Therm.	Reading	Reading corrected by Error of Instr.	*t. in situ*	Reading	Difference of Reading from *t. in situ*	Correction of Instrument	
June 23	10 m.	Grave	— 1·42° C.	— 1·63° C.	— 1·63° C.	— 1·56° C.	— 0·07° C.		
„ „	20 „	„	— 1·40 „	— 1·61 „	— 1·61 „	— 1·54 „	— 0·07 „		
„ „	60 „	„	— 1·54 „	— 1·75 „	— 1·75 „	— 1·66 „	— 0·09 „		
„ „	80 „	„	— 1·48 „	— 1·69 „	— 1·69 „	— 1·62 „	— 0·07 „		— 0·07° C.
„ „	100 „	„	— 1·36 „	— 1·57 „	— 1·57 „	— 1·53 „	— 0·04 „		
„ „	120 „	„	— 1·12 „	— 1·33 „	— 1·32 „	— 1·24 „	— 0·08 „		
„ 25	140 „	„	— 0·76 „	— 0·98 „	— 0·97 „	— 0·90 „	— 0·07 „		
„ „	160 „	„	— 0·48 „	— 0·70 „	— 0·69 „	— 0·62 „	— 0·07 „		
„ „	180 „	„	— 0·18 „	— 0·40 „	— 0·38 „	— 0·28 „	— 0·10 „		
„ „	200 „	„	— 0·07 „	— 0·29 „	— 0·27 „	— 0·22 „	— 0·05 „		
„ „	225 „	„	0·14 „	0·08 „	— 0·05 „	— 0·01 „	— 0·04 „		
„ „	250 „	„	0·65 „	0·43 „	0·47 „	0·52 „	— 0·05 „		— 0·07° C.
„ „	„ „	„	0·64 „	0·42 „	0·46 „	0·53 „	— 0·07 „		
„ „	275 „	„	0·43 „	0·21 „	0·26 „	0·33 „	— 0·07 „		
„ „	„ „	„	0·44 „	0·22 „	0·27 „	0·33 „	— 0·06 „		
„ „	300 „	„	0·65 „	0·43 „	0·49 „	0·58 „	— 0·09 „		
„ „	325 „	„	0·66 „	0·44 „	0·51 „	0·60 „	— 0·09 „		
„ 26	225 „	„	— 1·40 „	— 1·61 „	— 1·61 „	— 1·54 „	— 0·07 „		
„ „	225 „	„	0·12 „	— 0·10 „	— 0·07 „	0·01 „	— 0·08 „		
„ „	250 „	„	0·32 „	0·10 „	0·14 „	0·19 „	— 0·05 „		
„ „	275 „	„	0·34 „	0·12 „	0·17 „	0·23 „	— 0·06 „		
„ „	280 „	„	0·30 „	0·08 „	0·13 „	0·20 „	— 0·07 „		
„ „	290 „	„	0·68 „	0·46 „	0·52 „	0·58 „	— 0·06 „		
„ „	300 „	„	0·68 „	0·46 „	0·52 „	0·57 „	— 0·05 „		
„ „	310 „	„	0·70 „	0·48 „	0·54 „	0·60 „	— 0·06 „		
„ „	325 „	„	0·68 „	0·46 „	0·52 „	0·58 „	— 0·06 „		— 0·07° C.
„ „	„ „	„	0·45 „	0·23 „	0·29 „	0·35 „	— 0·06 „		
„ „	350 „	„	0·47 „	0·25 „	0·32 „	0·40 „	— 0·08 „		
„ „	375 „	„	0·48 „	0·26 „	0·33 „	0·41 „	— 0·08 „		
„ „	400 „	„	0·49 „	0·27 „	0·35 „	0·43 „	— 0·08 „		
„ „	425 „	„	0·49 „	0·27 „	0·35 »	0·44 „	— 0·09 „		
„ „	450 „	„	0·52 „	0·30 „	0·37 „	0·43 „	— 0·06 „		
„ „	500 „	„	0·40 „	0·18 „	0·25 „	0·35 »	— 0·10 „		
„ „	550 „	„	0·39 „	0·17 „	0·23 „	0·29 „	— 0·06 „		
„ 27	225 „	„	0·20 „	— 0·02 „	0·01 „	0·05 „	— 0·04 „		
„ „	250 „	„	0·47 „	0·25 „	0·29 „	0·32 „	— 0·03 „		
„ „	275 „	„	0·40 „	0·18 „	0·23 „	0·28 „	— 0·05 „		
„ „	300 „	„	0·52 „	0·30 „	0·36 „	0·35 „	+ 0·01 „		— 0·02° C.
„ „	325 „	„	0·56 „	0·34 „	0·40 „	0·40 „	0·00 „		
„ „	350 „	„	0·53 „	0·31 „	0·38 „	0·39 „	— 0·01 „		

Date 1894	Depth	Temperature by Water-Bottle				N. Z. 75682			
		Therm.	Reading	Reading corrected by Error of Instr.	*t. in situ*	Reading	Difference of Reading from *t. in stin*	Correction of Instrument	
Aug. 14	350 m.	Grave	0·43° C.	0·21° C.	0·28° C.	0·30° C.	— 0·02° C.		
„ „	375 „	„	0·43 „	0·21 „	0·28 „	0·30 „	— 0·02 „		
„ „	400 „	„	0·48 „	0·26 „	0·33 „	0·35 „	— 0·02 „		
„ „	450 „	„	0·47 „	0·25 „	0·32 „	0·36 „	— 0·04 „		
„ „	500 „	„	0·45 „	0·23 „	0·30 „	0·34 „	— 0·04 „		
„ „	550 „	„	0·35 „	0·13 „	0·19 „	0·22 „	— 0·03 „		
„ „	600 „	„	0·32 „	0·10 „	0·15 „	0·20 „	— 0·05 „		
„ „	650 „	„	0·32 „	0·10 „	0·14 „	0·18 „	— 0·04 „		
„ „	700 „	„	0·28 „	0·06 „	0·10 „	0·14 „	— 0·04 „		
„ „	800 „	„	0·20 „	— 0·02 „	0·01 „	0·07 „	— 0·06 „		
„ „	900 „	„	0·10 „	— 0·12 „	— 0·10 „	— 0·04 „	— 0·06 „		
„ „	1000 „	„	0·08 „	— 0·14 „	— 0·14 „	— 0·10 „	— 0·04 „		— 0·04° C.
Oct. 17	150 „	„	— 0·33 „	— 0·55 „	— 0·54 „	— 0·42 „	— 0·12 „		
„ „	300 „	„	0·87 „	0·65 „	0·71 „	0·80 „	— 0·09 „		— 0·105° C.
„ „	350 „	„	0·68 „	0·46 „	0·53 „	0·76 „	— 0·23 „		
„ „	400 „	„	0·61 „	0·39 „	0·46 „	0·78 „	— 0·32 „		
„ „	450 „	„	0·73 „	0·51 „	0·58 „	0·74 „	— 0·16 „		
„ „	500 „	„	0·62 „	0·40 „	0·47 „	0·62 „	— 0·15 „		
„ „	800 „	„	0·01 „	0·21 „	— 0·18 „	0·09 „	— 0·27 „		
„ „	1000 „	„	— 0·22 „	0·44 „	— 0·44 „	0·22 „	— 0·22 „		
Nov. 2	125 „	„	— 0·93 „	— 1·15 „	— 1·14 „	— 1·01 „	— 0·13 „		
„ „	150 „	„	— 0·30 „	— 0·52 „	— 0·51 „	— 0·40 „	— 0·11 „		— 0·12° C.
„ „	200 „	„	0·64 „	0·42 „	0·44 „	0·68 „	— 0·24 „		
„ „	310 „	„	0·78 „	0·56 „	0·62 „	0·88 „	— 0·26 „		
„ „	350 „	„	0·68 „	0·46 „	0·53 „	0·70 „	— 0·17 „		
„ „	400 „	„	0·80 „	0·58 „	0·65 „	0·70 „	— 0·05 „		

Remarks on the Tables. (1.) The errors of Negretti and Zambra No. 75682 appear to have been less stable on the first dates of observation, in April and May, than they were later. This may to some extent be owing to real variations in the errors of the indications, for such variations have evidently also occurred later (cf. June 22nd); but, as mentioned in the footnote on p. 23, it is also to a great extent owing to personal errors of observation, as I had not then so much experience in reading off the thermometers accurately, as I gradually acquired later, when (after June) I also used a lens for taking the readings. The irregularities in the differences between the indications of N. & Z. 75682

and the temperatures obtained by the water-bottle, are especially prominent in the series of April 14th and 15th, when they vary as much as between —0·09° C. and —0·24° C. for depths of less than 100 m., an incongruity of 0·15° C.; while the greatest difference between maximum and minimum in May is 0·12° C., and on most days of June amounts to 0·05° C., and in August there is very little irregularity. June 22nd is an exception, as on that day the differences vary between +0·09° C. and —0·08° C. It is probable that these irregularities are not solely owing to errors in the indications of the N. & Z. 75682; there may also have been some small irregularities in the indications of the thermometer of the water-bottle, and thus the uncertainty of the N. & Z. thermometer cannot be considered to be as great as it may appear from these tables.

(2.) According to what has been said before, it is to be expected that the most trustworthy temperature-readings should be those obtained by the insulated water-bottle from lesser depths, say down to 100 or 120 metres; for in these cases the temperature of the insulated water-sample cannot have been appreciably influenced by the colder water strata through which the water-bottle has to pass on its way to the surface, the temperature-differences in these strata being only a few tenths of a degree. We ought, therefore, chiefly to consider these temperatures when trying to find the corrections of the Negretti and Zambra thermometer No. 75682.

We have seen above that the mean differences between the readings of this thermometer and the temperatures obtained by the water-bottle from depths not exceeding 120 metres, give the following corrections for N. & Z. 75682

Date						Corrections
April	14 & 15,	1894,	mean	of 6	observations	—0·16° C.
May	22nd	„	„	„ 11	„	—0·09 „
June	22nd	„	„	„ 9	„	+0·02 „
„	23rd	„	„	„ 6	„	—0·07 „

The first correction, —0·16° C., may be expected to be the least trustworthy, as it is taken only from 6 comparisons with very different results, and then on those days the temperature of the air was about —18° C., so there is a probability that the temperature-readings of the thermometer of the water-bottle may throughout be somewhat too low (see pp. 8—10), perhaps as:

much as 0·04° C. We therefore probably come nearer the truth, if we suppose the correction of N. & Z. 75682 in April, 1894, to have been — 0·12° C.[1]

On May 22nd, 1894, the temperature of the air was about — 7° C., so from the same reason, the correction found for this date should perhaps be reduced a little, and thus we get — 0·08° C. instead of — 0·09° C. In June, the temperature of the air was very nearly the same as that of the water.

(3.) I have mentioned above, that the temperatures obtained by the insulated water-bottle for depths below 100 or 150 metres have to be reduced by corrections which I have tried to calculate (see tables, pp. 21, 24). Reduced in this way, the temperatures obtained by the water-bottle may be considered fairly accurate as long as the depths are not too great, although some errors may occur, caused by differences in the length of time required for hauling the water-bottle up, etc. On very cold days, however, such as October 17th and November 2nd, 1894, the results cannot be considered trustworthy (cf. p. 26), except perhaps for the lesser depths, where special care was taken to read off the temperature quickly, but even there some cooling may have occurred.

By comparing the indications of the instrument with the reduced temperatures obtained by the water-bottle from depths between 140 and 400 metres, we find the following corrections for N. & Z. No. 75682:

Date.						Correction of 75682.
April 15th and 23rd, 1894,	mean	of	10	observations		— 0·126° C.
May 22nd	„	„	6	„		— 0·08 „
June 25th	„	„	11	„		— 0·07 „
„ 26th	„	„	17	„		— 0·07 „
„ 27th	„	„	6	„		— 0·02 „
August 14th	„	„	12	„		— 0·04 „
October 17th	„	„	2	„	(for 150 and 300 m.)	— 0·105 „
November 2nd	„	„	2	„	(for 125 and 150 m.)	— 0·12 „

We see that these corrections agree fairly well with those found by considering merely the temperatures from the lesser depths.

For April 14th we found			— 0·12° C.,	here we find				— 0·126° C.
„ May 22nd	„	„	— 0·08	„	„	„	„	— 0·08 „
„ June 23rd	„	„	— 0·07	„	for June 25th and 26th we find			— 0·07 „

[1] Owing to the contraction of the broken-off column of mercury, caused by the exposure to the cold air, there is also a probability that the thermometer may have indicated slightly lower than it would otherwise have done (cf. p. 43).

June 22nd and 27th form, however, an exception, as on the former we found a correction of $+0{\cdot}02^0$ C., and on the latter we see it is $-0{\cdot}02^0$ C. It is probable that these irregularities are chiefly owing to irregular registering of the N. & Z. thermometer, and not so much to irregular errors in the temperature-readings obtained by the insulated water-bottle. Single temperature-readings taken by this reversing thermometer cannot, therefore, always be guaranteed with a higher degree of accuracy than $\pm 0{\cdot}09^0$ C., but as a rule will be about $\pm 0{\cdot}04^0$ C., and checked by the insulated water-bottle, the temperatures will naturally attain a still higher degree of accuracy.

The corrections found for October and November, 1894, have probably to be reduced by some hundredths of a degree, on account of the low temperature of the air (about -20^0 and -30^0 C.) on these days, which may have lowered the temperature-readings taken by the water-bottle. This does not, however, apply to the observations from about 150 metres (see what is said about these observations on p. 26).

(4.) It may at first seem strange that there should be so much variation in the errors of the instrument from one season to another, *e. g.* in April the correction should be $-0{\cdot}12^0$ C., whilst in August of the same year, it is $-0{\cdot}04^0$ C. Considering the secular contraction of the glass, one would rather expect the change to have gone in the opposite direction, which it also evidently has done on the whole, as in May, 1893, the zero-correction was $0{\cdot}00^0$ C., and in March, 1899, it was $-0{\cdot}21^0$ C. The variations, however, are evidently caused by the temporary contractions or expansions of the glass of the thermometer, which occur when the instrument is kept for any length of time at temperatures below or above the usual one; and the effect of this is especially marked in thermometers made of ordinary glass containing both sodium and potassium, and less in those made of 'Jena Normal-Glas' (16^{III}), or the French 'verre dur', or similar good glasses.[1]

According to Guillaume's experiments, the rise of the zero of a thermometer made of French 'verre dur', should be about $0{\cdot}03^0$ C., when the constant temperature to which the instrument is exposed is lowered from $+15^0$ C. to -20^0 C. If the thermometer be made of ordinary glass (con-

[1] Cf. Guillaume, '*Traité pratique de la Thermométrie de Précision*,' Paris, 1889, pp. 148, 149, and also table VI, p. 328.

taining potassium and sodium), the rise will be considerably higher, its magnitude depending on the composition of the glass. If the thermometer were made of French 'Cristal dur', the rise would probably be about 0·05° C., and if it were made of ordinary French 'cristal', it would be still higher.

N. & Z. No. 75682 was constantly exposed, during the cold season, to low temperatures, as, when it was not used, it was hanging in the chart-room on the upper deck, which was not heated, and where the temperature during the winter was certainly often below — 30° or — 40° C. This circumstance will naturally cause a rise of the zero of the instrument during the winter, in addition to that which is due to the regular secular contraction of the glass At the end of the winter, in April, we may therefore expect the rise of the zero to be at its highest; whilst we may expect it to be at its lowest, comparatively, at the end of the summer, in August, when it has for a long time been exposed to higher temperatures, above zero, perhaps 5 or 10° C. as it was hanging in the chart-room during the summer. But in the following winter, the rise of the zero will be higher than in the first winter, on account of the secular contraction of the glass. The following summer there will again be a depression of tbe zero, but it will not sink so low as the previous summer, etc.

The thermometers Müller No. 7 and R. Grave were generally kept in my cabin, which was heated during the winter. They were taken out for each observation, and thus they were not much exposed to low temperatures. It is not, therefore, to be expected that the temporary rise of the zero of these instruments has been of sufficient significance to be worthy of consideration here.

There are, however, also evident irregularities in the indications of the reversing thermometer, perhaps owing to some irregularity in the adhesion between the mercury and the inner walls of the glass-tube — especially near the contraction —, which sometimes prevents the disconnecting of the mercury at the contraction of the tube, and which may also cause small variations in the exact place of disconnection, *e. g.* on June 22nd and 27th. It is noteworthy that on certain dates the thermometer had a special liability to irregularities or to no disconnection, *e. g.* on May 15th and July 29th, 1895 (see also November 3rd, 1894). This may be owing to some kind of impurity in the mercury.

By drawing the probable curve for the variations of the zero of N. & Z. No. 75682, giving consideration to the secular as well as to the probable temporary changes, I find that the corrections have probably been the following for temperatures about zero:

Negretti and Zambra No. 75682.

Corrections for reducing the readings to the indications of the mercurial thermometer of 'verre dur'.

May, 1893	0·00° C.
April, 1894	— 0·12 „
May, 1894	— 0·08 „
June, 1894	— 0·07 „ [1]
August, 1894	— 0·04 „
October, 1894	— 0·10 „
November, 1894. . .	— 0·12 „
May, 1895	— 0·13 „
July, 1895	— 0·10 „
March, 1898	— 0·21 „

The corrections for May and July, 1895, are arrived at by supposing that the zero-correction has to some extent, not considering the temporary variations, been changed regularly by the secular rise of the zero from June, 1894 (— 0·07° C.), to March, 1898 (when it was — 0·21° C.). I have, however, also given consideration to the circumstance that the thermometer was, on the whole, regularly exposed to lower temperatures during the expedition, than it has been since August, 1896; the secular contraction of the glass was, therefore, probably comparatively slower during the years of the expedition, than it has subsequently been.

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[1] The correction found for June 22nd, 1894, by observations in depths between 10 m. and 40 m. differs a good deal from this correction, being + 0·02° C. But as it cannot be ascertained whether this irregularity is wholly owing to the errors of No. 75682, or also, to some extent, to errors in the temperatures taken by the water-bottle, I think it safer to use the correction — 0·07° C. also for this date. The results thus obtained agree well with the temperatures taken next day for the same depths (10 and 20 m.). The same also applies to the correction found for June 27th, which is — 0·02° C.

On the whole, I believe that we are justified in assuming that the degree of accuracy of these latter corrections is within a limit of ± 0·04° C., as long as the instrument has registered fairly regularly, which it appears to have done with few exceptions (cf. May 15th and July 29th, 1895)[1].

Negretti and Zambra No. 75684.

This instrument has not returned from the expedition. Its zero-correction in May, 1893, was ± 0·00° C.

In the first part of the following table, I give a series of observations taken in April, 1894, with this instrument simultaneously with N. & Z. No. 75682, or with Müller No. 7 and the insulated water-bottle. By correcting the indications of Müller No. 7, and N. & Z. No. 75682 (see the fifth column), I find the corrections for No. 75684, which are given in the seventh column. The means of these corrections are (see the eighth column) — 0·16° C. for the comparisons with Müller No. 7, and — 0·14° C. for the comparisons with N. & Z. No. 75682. In the former case, the temperatures obtained by the water-bottle (and Müller No. 7) may be 0·04° C. too low, owing to the low temperature of the air on that day (see above); and the correction should accordingly be — 0·12° C.

The corrections for April 23rd—26th, 1894, are taken from the series of water-temperatures taken alternately in the various depths by this instrument and by N. & Z. No. 75682. The corrections are determined by interpolation between the temperatures found by 75682 for the nearest depths above and below, *e. g.* the corrected temperature found by 75682 for 600 m. is 0·08° C. and for 800 m. is — 0·13° C.; the temperature for 700 m. should then be — 0·02° C. The indication of N. & Z. No. 75684 for 700 m. is, however, 0·10° C., the correction of the instrument should consequently be — 0·12° C. Only those depths are used, where the variation of the water-strata appears

[1] On May 14th, 1895, Capt. Scott-Hansen and Dr. Blessing tested the zero of this thermometer in melting hoar-frost, and by 9 readings they determined the zero-correction to be — 0·4° C. But on a later occasion, Blessing remarks in the journal that he does not regard the method used for these determinations as very trustworthy, as the indications of the thermometer were somewhat elevated by his keeping it in his hand during the turning over, etc. As, on the whole, this high correction appears to be very improbable, and as zero-corrections of these instruments must be taken with great care if they are not to be misleading, I think it right to leave this determination out of consideration.

to be regular. The mean value of the corrections found in this way is — 0·11° C.

In three different ways, we have consequently found the following corrections for N. & Z. No. 75684 in April, 1894: — 0.12° C., — 0.14° C., and — 0.11° C. The mean value of these is — 0.12° C., which I accept as the correction for the instrument at that time.

Corrections for N. & Z. No. 75684.

Date 1894	Depth	Therm.	Temperature		N. & Z. 75684		
			Reading	Reading corrected to *t. in situ*	Reading	Difference of Reading from *t. in situ*	Correction of Instrument
April 14th	60 m.	Müller 7	— 1·85° C.	— 1.91° C.	— 1·60° C.	— 0·31(?)° C.	— 0·16° C.
„ 15th	80 „	„	— 1·75 „	— 1·81 „	— 1·72 „	— 0·09 „	
„ „	100 „	„	— 1·63 „	— 1·68 „	— 1·50 „	— 0·18 „	
„ „	120 „	„	— 1·55 „	— 1·59 „	— 1·43 „	— 0·16 „	
„ „	140 „	„	— 1·25 „	— 1·26 „	— 1·20 „	— 0·06 „	
„ „	180 „	„	— 0·45 „	— 0·39 „	— 0·25 „	— 0·14 „	
April 14th	60 m.	75682	— 1·67 „	— 1·79 „	— 1·60 „	— 0·19 „	— 0·14° C.
„ 15th	80 „	„	— 1·61 „	— 1·73 „	— 1·72 „	— 0·01 „	
„ „	100 „	„	— 1·60 „	— 1·72 „	— 1·50 „	— 0·22 „	
„ „	120 „	„	— 1·44 „	— 1·56 „	— 1·43 „	— 0·13 „	
„ „	140 „	„	— 1·22 „	— 1·34 „	— 1·20 „	— 0·14 „	
„ „	180 „	„	— 0·27 „	— 0·39 „	— 0·25 „	— 0·14 „	

Probable error found by interpolation between two observations taken from the nearest depths above and below, with N. & Z. 75682, Müller 7, and Grave:

Date 1894	Depth	Therm.	*t. in situ* found by inter-polation	N. & Z. 75684		
				Reading	Difference of Reading from *t. in situ*	Correction of Instrument
April 23rd	350 m.	75682	0·22° C.	0·28° C.	(— 0·06)° C.[1]	
„ „	550 „	„	0·17 „	0·22 „	(— 0·05) „[1]	
„ 24th	700 „	„	— 0·02 „	0·10 „	— 0·12 „	— 0·11° C.
„ „	900 „	„	— 0·17 „	0·00 „	— 0·17 „	
„ „	1100 „	„	— 0·30 „	— 0·20 „	— 0·10 „	
„ „	1300 „	„	— 0·45 „	— 0·38 „	— 0·07 „	
„ „	1500 „	„	— 0·58 „	— 0·30 „	(— 0·28?) „	
„ 26th	1500 „	„	— 0·59 „	— 0·48 „	— 0·11 „	
„ 25th	1700 „	„	— 0·71 „	— 0·62 „	— 0·09 „	
„ „	1900 „	„	— 0·79 „	— 0·69 „	— 0·10 „	

[1] The temperature varies so much in these depths, that no trustworthy results are obtained by interpolation.

Date 1894	Depth	Therm.	*t. in situ.* found by inter-polation	N. & Z. 75684		
				Reading	Difference of Reading from *t. in situ.*	Correction of Instrument
May 22nd	30 m.	75682	− 1·69 ° C.	− 1·55 ° C.	− 0·14 ° C.	
„ „	„ „	Müller 7	− 1·705 „	− 1·55 „	− 0·155 „	
„ „	„ „	Grave	− 1·655 „	− 1·55 „	− 0·105 „	
„ „	50 „	Müller 7	− 1·74 „	− 1·65 „	− 0·09 „	
„ „	„ „	75682	− 1·715 „	− 1·65 „	− 0·065 „	
„ „	70 „	Müller 7	− 1·77 „	− 1·64 „	− 0·13 „	
„ „	„ „	75682	− 1·73 „	− 1·64 „	− 0·09 „	
„ „	90 „	Müller 7	− 1·705 „	− 1·60 „	− 0·105 „	
„ „	„ „	75682	− 1·67 „	− 1·60 „	− 0·07 „	
„ „	110 „	Müller 7	− 1·555 „	− 1·46 „	− 0·095 „	
„ „	„ „	75682	− 1·51 „	− 1.46 „	− 0·05 „	− 0·10° C.
„ 23rd	550 „	„	0·22 „	0·24 „	(− 0·02) „ [1]	
„ 24th	650 „	„	0·09 „	0·18 „	− 0·09 „	
„ „	750 „	„	0·015 „	0·04 „	− 0·055 „	
„ „	850 „	„	− 0·09 „	− 0·01 „	− 0·08 „	
„ „	950 „	„	− 0·145 „	− 0·06 „	− 0·085 „	
„ „	1050 „	„	− 0·265 „	− 0·22 „	− 0·045 „	
„ „	1300 „	„	− 0·42 „	− 0·41 „	− 0·01 „	− 0·07° C.
„ 25th	1500 „	„	− 0·55 „	− 0·47 „	− 0·08 „	
„ „	1700 „	„	− 0·66 „	− 0·60 „	− 0·06 „	
„ „	1900 „	„	− 0·745 „	− 0·64 „	− 0·105 „	
„ „	2100 „	„	− 0·80 „	− 0·74 „	− 0·06 „	
August 15th	1300 „	„	− 0·35 „	− 0·30 „	− 0·05 „	
„ „	1500 „	„	− 0·44 „	− 0·44 „	0·00 „	− 0·03° C.
„ „	1700 „	„	− 0·57 „	− 0·57 „	0·00 „	
„ „	1900 „	„	− 0·69 „	− 0·64 „	− 0·05 „	

By comparison with interpolations between the temperatures taken from depths between 20 m. and 120 m. by N. & Z. 75682, and by the insulated water-bottle (and the thermometers Müller No. 7 and R. Grave), on May 22nd, we find that the mean value of the differences gives a correction for N. & Z. No. 75684, of − 0·10° C. Although these corrections are found by interpolation between the temperatures taken from the nearest depths above and below those at which the observations with No. 75684 are made, they may be considered fairly accurate, because the temperature changes very little and regularly in these depths.

The corrections for the succeeding days of May, 1894, are found in the same way by interpolation between the corrected indications of N. & Z.

[1] The temperature varies so much in this depth, that no trustworthy results are obtained by interpolation.

No. 75682, from depths between 600 m. and 2200 m. The corrections found by averaging the differences is — 0·07° C. The mean value of the two corrections found for May, 1894, is — 0.08° C.

On August 15th, 1894, there are four observations which, by comparison with the indications of No. 75682 for the nearest depths, give a mean correction of — 0·03° C.

There are no observations for determining the corrections of this instrument for other days, but as, on the whole, they appear to have followed those of No. 75682 fairly closely, I have drawn a similar curve for their variations, and have thus found the following corrections:

Negretti and Zambra No. 75684.

Corrections for reducing the readings to the indications of the mercurial thermometer of "verre dur".

May, 1893	0·00° C.
April, 1894	— 0·12° C.
May, 1894	— 0·08° C.
August, 1894	— 0·03° C.
October, 1894	— 0·10° C.
May, 1895	— 0·13° C.[1]
July, 1895	— 0·10° C.
November, 1895 . . .	— 0·16° C.

Negretti and Zambra No. 75680.

The zero-corrections of this instrument were found by Prof. Mohn to be:

in May, 1893	+ 0·07
in March, 1898	± 0·00.

[1] On May 28th, 1895, Capt. Scott-Hansen determined the zero-correction of N. & Z. 75684 to be — 0·2° C. The determination was made in melting hoar-frost, and the thermometer was enclosed in the brass cylinder of the turning apparatus, as the screw at the end of the cylinder was fixed by corrosion, so that it was difficult to get out. Although this determination does not appear to be improbable, it can hardly be considered to be quite trustworthy (cf. Blessing's remark in the footnote, p. 58).

This instrument was used during the two last years of the expedition, 1895 and 1896, by Dr. Blessing. Only on July 29th, 1895, are there simultaneous observations with this instrument and other thermometers. These observations are given in the following tables:

Comparisons between N. Z. 75682, and N. Z. 75680.

1895	Depth	*N. Z. 75682*		*N. Z. 75680*	
		Reading	Corrected Temperature	Reading	Correction
July 29th	160 m.	— 0·70° C.	— 0·80° C.	— 0·80° C.	— 0·00° C.
„ „	180 „	0·45 „	0·35 „	— 0·10 „	(+ 0·45?) „
„ „	200 „	0·75 „	0·65 „	0·47 „	(+ 0·18) „
„ „	„ „	0·75 „	0·65 „	0·35 „	(+ 0·30) „
„ „	250 „	1·00 „	0·90 „	1·15 „	— 0·25 „

Comparisons between N. Z. 75684, and N. Z. 75680.

1895	Depth	*N. Z. 75684.*		*N. Z. 75680.*		
		Reading	Corrected Temperature	Reading	Correction	
July 29th	350 m.	1·25° C.	1·15° C.	1·20° C.	— 0·05° C.	— 0·06° C.
„ „	400 „	1·05 „	0·95 „	1·00 „	— 0·05 „	
„ „	500 „	0·79 „	0·69 „	0·77 „	— 0·08 „	
„ „	600 „	0·62 „	0·52 „	0·60 „	— 0·08 „	

The corrections found in these tables by comparison with the temperatures taken by No. 75682 are evidently not trustworthy, as there was something wrong with No. 75682, and it registered very irregularly on that day (see the series of deep-sea temperatures for July 29th, 1895, below).

The four comparisons with No. 75684 (in the second table) seem to give very good results, and according to these, the correction of N. & Z. No. 75680 should be about — 0·06° C. for July, 1895. This correction does not, however, appear to correspond very well with the zero-correction found for March, 1898, which was 0·00° C.; for, considering the secular contraction of the glass of the thermometer, it is hardly probable that the elevation of the zero of the instrument would have been greater in the summer of 1895, than in the winter, of

1898. But as it is not impossible that there may have been a temporary contraction of the glass in July, 1895, or some irregularity in the determination of the zero-correction of March, 1898, and as, on the whole, it agrees better with the observations taken with the other instruments, I accept the correction — 0·06° C. for N. & Z. No. 75680, for 1895 and 1896. The real errors may vary between that and 0·00° C., but as there is no material for a calculation of the variations, I assume the correction to be the same for the whole time, and the error thus obtained can hardly exceed ± 0·06° C.[1]

The thermometers mentioned below were used by Capt. Scott-Hansen and his meteorological assistants for taking the temperature of the sea-surface and the uppermost strata of the sea.

The instruments were made for the expedition by Mr. Söderberg in Stockholm, according to the order of Prof. Mohn. They were mercury thermometers of two sizes: a small size (Sbg. Nos. 16, 20, 22, 25) divided into whole degrees Centigrade, and a larger size (Sbg. Nos. 105, 107, 111, 114, 118) divided into fifths of degrees Centigrade. The thermometers will be described by Prof. Mohn in his Memoir on the Meteorology, and I shall here only give their errors of the zero-point, determined in April and May, 1893, by Prof. Mohn, and on the later dates by Capt. Scott-Hansen. The zero-corrections for the intervening or subsequent dates may be found by drawing the probable curve for the rise of the zero. As the sea-temperature readings taken, with a few exceptions, are only a few degrees below or above zero,

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[1] On February 5th, 1896, Dr. Blessing tested the zero of this instrument in melting hoar-frost where no traces of salt could be discovered by $AgNO_3$. When the hoar-frost began to melt, the following readings were taken:

0·27° C.	0·40° C.
0·30 „	0·40 „
0·35 „	0·40 „
	0·40 „

The zero-correction should consequently be about — 0·40° C. Dr. Blessing adds, however, that he sees that the method used for determining the correction cannot be trustworthy, as the mercury would rise somewhat, by his keeping the thermometer in his hand while it was turned. As a correction of as much as — 0·4° C. appears to be very improbable, I leave these determinations out of consideration.

they may be reduced by the error of the latter without incurring the risk of any considerable error.

Söderberg No. 16 (= Sbg. 16).

Small size, divided into whole degrees Centigrade.

Date.	*Zero-correction.*
May, 1893	+ 0·1 ° C.
October, 1893	— 0·05 „

The thermometer was broken on November 28th, 1893.

Söderberg No. 20 (= Sbg. 20).

Small size, divided into whole degrees Centigrade.

This thermometer was much used for taking the temperature of the water-samples while they were being examined by the hydrometer.

Date	*Zero-correction*	*Correction at 11° C.*
May, 1893	— 0·0 ° C.	— 0·1 ° C.
February 1st, 1894	— 0·1 „	
„ „ „	— 0·09 „	
„ „ „	— 0·09 „	
„ „ „	— 0·09 „	
April 12th, 1894	— 0·25 „	(— 0·35 „)
April 23rd, 1894		— 0·33 „

On April 23rd, 1894, seven comparisons between this thermometer and Küchler No. 1 are recorded in the journal, giving the following correction for Söderberg No. 20, for temperature-readings between 11·2° C. and 12·0° C.

Temperature-reading	*Correction*
11·2 ° C.	— 0·36° C.
11·3 „	— 0·32 „
11·4 „	— 0·33 „
11·6 „	— 0·38 „
11·9 „	— 0·29 „
11·95 „	— 0·29 „
12·0 „	— 0·29 „

By two comparisons with Müller No. 7 on the same date the following corrections were found.

Temperature-reading	*Correction*
11·2° C.	— 0·39° C.
11·4 „	— 0·36 „

The mean value of the 9 determinations gives us a correction of — 0·33° C. for indications between 11° C. and 12° C. This would give a zero-correction of — 0·23° C., which agrees well with the correction of — 0·25° C. found on April 12th, 1894.

Söderberg No. 22 (= Sbg. 22).

Small size, divided into whole degrees Centigrade.

Date	*Zero-correction*
May, 1893	0·00° C.
December, 1893	0·00 „

The latter error seems to be improbable, as the rise of the zero in the other Söderberg thermometers was between 0·09° C. and 0·17° C. or even more, from May to December, 1893. I have therefore assumed a similar rise of the zero in this instrument.

Söderberg No. 25 (= Sbg. 25).

Small size, divided into whole degrees.

In May, 1893, the error of this thermometer was determined by Mohn to be ± 0·00° C. along the whole scale. No later determination of the error of the instrument is recorded in the journals, and it was broken on the 13th September, 1893. Provided that the rise of the zero has been about the same as in the other Söderberg thermometers, we may easily find the error of the zero for the intervening dates by aid of a diagrammatic curve; and we may thus assume that from July 21st to September 13th, 1893, the error of the instrument was — 0·1° C.

Söderberg No. 105 (= Sbg. 105).

Larger size, divided into 0·2° C.

Date	*Zero-correction*	*Date*	*Zero-correction*
April, 1893	+ 0·20° C.	February 27th, 1894	+ 0·15° C.
December 19th, 1893	+ 0·11 „	April 12th, 1894	+ 0·13 „
February 1st, 1894	+ 0.1 „	May 28th, 1895	+ 0·03 „
„ „ „	+ 0·12 „	August 30th, 1895	+ 0·04 „
„ „ „	+ 0·1 „		
„ „ „	+ 0·2 „		
„ „ „	+ 0·15 „		

Söderberg No. 107 (= Sbg. 107).

Larger size, divided into 0·2° C.

Date	*Zero-correction*
April, 1893	+ 0·20° C.

There are no later determinations of the zero-correction, but we may certainly assume that the rise of the zero has been similar to that found in the sister thermometers.

Söderberg No. 111 (= Sbg. 111).

Larger size, divided into 0·2° C.

Date	*Zero-correction*
April, 1893	+ 0·20° C.
December 19th, 1893	+ 0·08 „

Söderberg No. 114 (= *Sbg. 114*.).

Larger size, divided into 0·2 ° C.

Date	*Zero-correction*	*Date*	*Zero-correction*
April, 1893	. . . + 0·20° C.	February 1st, 1894	. . . + 0·06° C.
October 18th, 1893	. . . + 0·05 „	„ „ „	. . . + 0·06 „
December 19th, 1893	. . . + 0·05 „	„ „ „	. . . + 0·06 „
February 1st, 1894	. . . + 0·05 „	February 4th, 1894	. . . + 0·05 „
		May 8th, 1894	. . . + 0·05 „

Söderberg No. 118 (= *Sbg. 118*).

Larger size, divided into 0·2 ° C.

Date	*Zero-correction*	*Date*	*Zero-correction*
April, 1893	. . . + 0·20° C.	May 8th, 1894	. . . ± 0·00° C.
October 18th, 1893	. . . + 0·03 „	August 30th, 1895	. . . + 0·04 „

Casella No. 72327 (= *Ca. 27*)

is a mercurial sling-thermometer originally ordered for my expedition across Greenland in 1888. It is 15·7 cm. long. The scale ranges from — 30° C. to + 21° C., and is divided into whole degrees Centigrade. On May 6th, 1895, Capt. Scott-Hansen compared this thermometer with other thermometers and found a correction of — 0·1° C. The following determinations of the zero-corrections were also made.

Date	*Zero-correction*
May 6th, 1895	— 0·1 ° C.
„ 11th, „	— 0·15 „

II.

OBSERVATIONS.

A. THE TEMPERATURE OF THE SURFACE OF THE SEA.

The temperature of the sea-surface was taken by Capt. Scott-Hansen or by his meteorological assistants. During the voyage across the Barents Sea and along the Siberian coast, these observations were taken every four hours by immersing a thermometer in a bucket of water which was hauled on deck from the sea-surface near the bow of the ship. These observations cannot, therefore, pretend to any very high degree of accuracy.

During the first period of the drifting of the Fram in the ice, after September, 1893, the temperature of the sea-surface was taken in a similar way, through a hole in the ice-floe, on the port side of the ship, and about 50 metres distant from her. At this place a crack had been formed parallel with the ship during the first winter; a channel some few metres broad was here formed, and was covered with ice which, however, never grew as thick as the surrounding floe. The hole was made through this thinner ice, and was kept open during the first winter. During the second and third winters, similar holes were kept open. The temperature-readings were taken either in a water-bucket, which was filled at the water-hole and placed on the ice, or by immersing the thermometer directly in the surface-water in the hole, and reading it there. As the temperature of the sea-surface changed very slowly and slightly in the ice, after Sept. 26th, 1893, and for long periods remained nearly constant, the temperature was here taken at first only once a day, and subsequently often at much greater intervals.

After June 14th, 1894, Scott-Hansen began, at certain intervals, to take series of temperatures, from 0 metres down to 3 metres or deeper, which give interesting results with regard to the influence of the melting of the ice upon the vertical distribution of temperature in the upper water-strata, etc. When not otherwise stated, these observations were taken with a glass bottle (an ordinary beer-bottle) which was fixed to the end of a rod, divided into metres. The bottle was lowered by this rod to the exact depth desired, and was then filled by removing the cork, to which a string was attached.

These series of temperatures were taken partly in the 'water-hole' in the ice-floe on the port side of the ship, partly in other narrow channels, or in broader lanes in the ice; and the vertical distribution of temperature generally differs somewhat in these various places, as may be seen from the following table.

TABLE.

The columns of the following table give:

First column, Date of Observation.

Second column, Hour of Observation.

Third column, North Latitude of Observation.

Fourth column, Longitude east of Greenwich.

Fifth column, The Wind. For the time from Oct. 1st, 1893, to April 30th, 1896, the letters indicate approximately the true direction of the wind, and the numbers the velocity per second in metres. For the first part of the voyage, before Oct. 1st, 1893, and the last part, after April 30th, 1896, the direction of the wind and its velocity are simply taken out of the journal, as there has not yet been time to correct them. The former should be corrected by the declination and the deviation of the compass; the speed of the ship while moving, will also cause an error for which the direction of the wind, as well as the velocity, has to be corrected.

Sixth column, the approximate Temperature of the Air.

Seventh column, Description of the Clouds by the usual terms (cir. = cirrus, str. = stratus, etc.), and by numbers giving the amount of Cloud from 0 = a clear sky, to 10 = a sky completely overcast.

Eighth column, the Depth in Metres.

Ninth column, Designation of Thermometer.

Tenth column, Temperature-reading in Centigrade.

Eleventh column, Error of the Thermometer.

Twelfth column, Temperature in Centigrade, corrected for Instrumental Error.

Thirteenth column, Remarks.

The dashes in the columns indicate a repetition of the next preceding figures or words above.

TABLE

SHOWING THE TEMPERATURES OF THE SEA-SURFACE AND THE UPPER WATER-STRATA.

BY CAPT. SIGURD SCOTT-HANSEN.

Date. 1893.	Hour.	North Lat.	East Long.	Wind. Magn. Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.		Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
July 21	7 p. m.	70° 31′	34° 3′	SSE	3·0	9·3° C.	Fog	10	0 m.	Sbg. 25	8·1° C.	− 0·1	8·0° C.	
	Midn.			ESE	3·0	6·8 -	-	10	0 -	-	7·0 -	-	6·9 -	
July 22	4 a. m.			SSE	3·6	10·0 -	-	10	0 -	-	6·2 -	-	6·1 -	
	9 a. m.			E b N	4.3	8·6 -	-	10	0 -	-	7·2 -	-	7·1 -	
	0.30 p. m.	70° 38′	37° 28′	E b N	5·8	7·0 -	-	10	0 -	-	5·8 -	-	5·7 -	
	4 p. m.			ENE	4·4	8·8 -	-	10	0 -	-	6·0 -	-	5·9 -	
	7 p. m.					6·9 -	-	10	0 -	-	6·1 -	-	6·0 -	
	8 p. m.			ENE	5·8	6·3 -	-	10	0 -	-	5·75 -	-	5·65 -	
	Midn.			E b N	4·2	6·0 -	-	10	0 -	-	6·0 -	-	5·9 -	
July 23	4 a. m.			ENE	5·5	6·0 -	-	10	0 -	-	6·0 -	-	5·9 -	
	8 a. m.	70° 53′	41° 23′	ENE	5·5	6·0 -	Mist.	9	0 -	-	6·0 -	-	5·9 -	
	Noon.			N b E	5·2	5·3 -	Fog	10	0 -	-	5·7 -	-	5 6 -	
	4 p. m.			NE b N	6·0	5·3 -	-	10	0 -	-	5·1 -	-	5·0 -	
	8 p. m.			NE b E	4·2	5·2 -	-	10	0 -	-	5·2 -	-	5·1 -	
	10 p. m.			NE	4	4·1 -	-	10	0 -	-	5·2 -	-	5·1 -	
	Midn.			NE	3·3	3·8 -	-	10	0 -	-	5·0 -	-	4·9 -	
July 24	4 a. m.			N	5·2	3·8 -	-	10	0 -	-	4·8 -	-	4·7 -	
	8 a. m.	71° 11′	46° 13′	N	3·3	3·7 -	-	10	0 -	-	4·1 -	-	4·0 -	
	1 p. m.			NW b W	2·4	4·3 -	Light mist	9	0 -	-	5·0 -	-	4·9 -	
	4·30 p. m.			NNE	4·0	3·6 -	Light mist	9	0 -	-	4·8 -	-	4·7 -	
	8 p. m.			NNE	5·4	3·2 -	Fog	10	0 -	-	5·0 -	-	4·9 -	
July 25	4 a. m.			NNE	4·4	2·8 -	-	10	0 -	-	4·5 -	-	4·4 -	
	8 a. m.			E b S	3·2	6·2 -	0	0	0 -	-	4·8 -	-	4·7 -	
	1 p. m.			ESE	7·0	7·0 -	0	0	0 -	-	5·5 -	-	5·4 -	
	5 p. m.	71° 23′	51° 32′	SE	8·8	7·6 -	Fog	10	0 -	-	7·5 -	-	7·4 -	

July 25	8 p. m.			SE	7·0	6·4 -	-	10	0 -	-	6·0 -	-	5·9 -			
	Midn.			E	11·0	7·2 -	Misty	5	0 -	-	5·5 -	-	5·4 -			
July 26	4 a. m.			E	20·6	4·3 -	Fog	10	0 -	-	5·0 -	-	4·9 -			
	8 a. m.			E	12·1	3·8 -	Misty	5	0 -	-	5·0 -	-	4·9 -			
	Noon.	70° 27′	51° 31′	ESE	9.0	4·2 -	Fog	8	0 -	-	4·8 -	-	4·7 -			
	4 p. m.			E	5·3	4·9 -	-	10	0 -	-	4·8 -	-	4·7 -			
	8 p. m.			SE	4·4	4·8 -	-	10	0 -	-	4·7 -	-	4·6 -			
	Midn.			Calm		4·9 -	-	10	0 -	-	4·0 -	-	3·9 -			
July 27	4 a. m.			SE	4·5	4·2 -	-	10	0 -	-	4·0 -	-	3·9 -			
	8 a. m.	69° 46′	53° 55′	SE	4·2	7·0 -	Misty	8	0 -	-	6·5 -	-	6·4 -			
	Noon.			SE	4·7	7·6 -	-	4	0 -	-	8·3 -	-	8·2 -			
	3.45 p. m.								0 -	-	7·6 -	-	7·5 -			
	4 p. m.			SE b E	4·4	4·7 -	Cir.	2	0 -	-	5·7 -	-	5·6 -	A few pieces of ice were seen.		
	6 p. m.			SE	3·3	4·2 -	Mist. & Cir.	5	0 -	-	3·9 -	-	3·8 -	Passed through a belt of ice-floes.		
	8 p. m.			SE	5·7	5·8 -	Ci.cu.st.	8	0 -	-	5·7 -	-	5·6 -	At 7.30 p. m. sailed out of ice into open sea again.		
	Midn.			SE	5·3	6·8 -	Ci.cu.st.	3	0 -	-	7·0 -	-	6·9 -			
July 28	4 a. m.			SSE	5·8	7·2 -	Ci.cu.st.	6	0 -	-	7·0 -	-	6·9 -			
	8 a. m.			0	0	5·7 -	Cu.st. & mist.	8	0 -	-	2·5 -	-	2·4 -	Was stopped by ice at 6 a. m.		
	Noon.	69° 25′	57° 7′	W b S	2·5	5·1 -	Fog	10	0 -	-	2·8 -	-	2·7 -	In the ice.		
	5 p. m.			WSW	2·6	4·8 -	-	10	0 -	-	2·0 -	-	1·9 -	In the ice.		
	8 p. m.			W	3·1	5·2 -	-	10	0 -	-	2·5 -	-	2·4 -	Scattered ice. Current running west.		
July 29	1.45 a. m.			NW	5·3	5·2 -	Strat.	10	0 -	-	0·7 -	-	0·7 -	Fairly slack ice.		
	4 a. m.			NW	7·4	7·4 -	-	8	0 -	-	7·5 -	-	7·4 -	Open sea.		
	8 a. m.			NW	5·2	5·2 -	0	0	0 -	-	6·5 -	-	6·4 -	—		
	Noon.	69° 34′	59° 12′	NW b W	6·0	5·8 -	Cum.str.	9	0 -	-	5·5 -	-	5.4 -	—		
	6 p. m.	Mouth of Yugor Strait		W b N	4·2	6·6 -	-	9	0 -	-	5·5 -	-	5·4 -	No ice.		
	8 p. m.	69° 41′	60° 20′	S	1·0	6·7 -	-	9	0 -	-	6·3 -	-	6·2 -	Khabarova.		
	Midn.	-	-	S	5·7	4·4 -	Strat.	9	0 -	-	4·3 -	-	4·2 -	—		
July 30	8 a. m.	-	-	N	4·4	5·3 -	Cum.str.	8	0 -	-	3·3 -	-	3·2 -	—		
	Noon.	-	-	N	5·2	4·1 -	-	7	0 -	-	3·5 -	-	3·4 -	—		
	8 p. m.	-	-	N	2·2	3·6 -	-	7	0 -	-	4·5 -	-	4·4 -	—		
July 31	4 a. m.	-	-	SW	1·8	5·6 -	-	6	0 -	-	3·8 -	-	3·7 -	—		
	8 a. m.	-	-	W	4·1	6·2 -	Strat.		0 -	-	4·6 -	-	4·5 -	—		
	Noon.	-	-	W	3·3	6·8 -	-		0 -	-	5·0 -	-	4·9 -	—		

Date. 1893.	Hour.	North Lat.	East Long.	Wind. Magn. Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
July 31	8 p. m.	69° 41′	60° 20′	WNW	3·3	3·9° C.	Cum.str. 8	0 m.	Sbg. 25	3·3° C.	— 0·1	3·2° C.	Khabarova.
	Midn.	-	-	WNW	2·3	2·4 -	- 2	0 -	-	2·8 -	-	2·7 -	—
Aug. 1	5 a. m.	-	-	Calm		2·3 -	0 0	0 -	-	2·8 -	-	2·7 -	—
	Noon.	-	-	S	1·6	2·8 -	Fog 10	0 -	-	2·9 -	-	2·8 -	—
	4 p. m.	-	-	SE	4·4	3·4 -	Strat. 8	0 -	-	3·0 -	-	2·9 -	—
Aug. 2	10 a. m.	-	-	SSE	7·2	9.6 -	Cum.str.	0 -	-	3·1 -	-	3·0 -	—
	9 p. m.	-	-	SSE	7·2	10·05 -	- 9	0 -	-	4·8 -	-	4·7 -	—
Aug. 3	8 a. m.	-	-	WSW	3·2	7·5 -	Fog 10	0 -	-	7·3 -	-	7·2 -	—
	Noon.	-	-	WSW	2·6	7·9 -	- 10	0 -	-	5·25 -	-	5·15 -	—
	6 p. m.	-	-	N	5.7	6·9 -	Strat. & mist. 10	0 -	-	6·1 -	-	6·0 -	—
	Midn.	-	-	N	5·8	3·0 -	Fog 10	0 -	-	5·0 -	-	4·9 -	—
Aug. 4	4 a. m.	East end of Yugor Strait		N	5·9	1·95 -	Strat. 10	0 -	-	3·0 -	-	2·9 -	Small pieces of floe-ice.
	8 a. m.			N		2·20 -		0 -	-	3·0 -	-	2·9 -	
	4 p. m.			NW		1·4 -	Cum.str. 8	0 -	-	2·8 -	-	2·7 -	Rather scattered ice.
	8 p. m.			Calm		1·4 -	Cir.cum. 7	0 -	-	1·5 -	-	1·4 -	Rather scattered ice.
	Midn.			-		2·0 -		0 -	-	2·0 -	-	1·9 -	
Aug. 5	4 a. m.	Off Kara River		Calm		0·8 -		0 -	-	2·0 -	-	1·9 -	
	8 a. m.			ESE	0	1·4 -	Cum.str. 9	0 -	-	1·1 -	-	1·0 -	Scattered ice.
	Noon.	69° 38′	65° 46′	ESE		1·3 -	Strat. 10	0 -	-	1·0 -	-	0·9 -	Scattered ice.
	5 p. m.			W	3·1	1·8 -	Fog 10	0 -	-	0·7 -	-	0·6 -	Rather tight ice.
	8 p. m.			W	3·8	1·7 -	- 10	0 -	-	0·4 -	-	0·3 -	Tight ice. Current running north.
	Midn.			S	2·5	1·7 -	Cum. & mist. 7	0 -	-	0·6 -	-	0·5 -	Rather tight ice.
Aug. 6	4 a. m.			W	3·3		10	0 -	-	0·7 -	-	0·6 -	Scattered ice.
	8 a. m.	69° 37′	66° 43′	WNW	3·8	3·1 -	Strat. 10	0 -	-	0·6 -	-	0·5 -	Moored to an ice-floe a mile off Yalmal Coast.
	1 p. m.	-	-	WNW	5·2	2·0 -	Fog 10	0 -	-	1·0 -	-	0·9 -	—
	4 p. m.	-	-	NW	4·5	1·4 -	Mist. 9	0 -	-	0·95 -	-	0·85 -	—
	8 p. m.	-	-	NW	4·3	1·2 -	Ci.cu.st. 0·5	0 -	-	0·9 -	-	0·8 -	—
	Midn.	-	-	NW	3·5	0·2 -	Fog 10	0 -	-	0·0 -	-	— 0·1 -	—

Aug. 7	4 a.m.	69° 37′	66° 43′	NW 3·9	— 0·5 -	0·5	0 -	-	— 0·2 -	-	— 0·3 -	—
	8 a.m.	-	-	NW b W 2·6	3·8 -	Misty 0·5	0 -	-	1·0 -	-	0·9 -	—
	Noon.	-	-	WNW 3·2	2·0 -	- 0·5	0 -	-	0·5 -	-	0·4 -	—
	4 p.m.	-	-	Calm	2·5 -	Strat. 10	0 -	-	1·0 -	-	0·9 -	—
	8 p.m.	-	-	-			0 -	-	1·0 -	-	0·9 -	—
	Midn.	-	-	S 1·7	3·0 -	Hazy 5	0 -	-	1·2 -	-	1·1 -	—
Aug. 8	4 a.m.	-	-	SE b S 3·7	3·5 -	Hazy 8	0 -	-	0·8 -	-	0·7 -	—
	8 a.m.	-	-	SE b S 5·2	4·6 -	Strat. 10	0 -	-	0·75 -	-	0·65 -	—
	Noon.	-	-	SE b E 8·0	0·0 -	- 2	0 -	-	— 1·1 -	-	— 1·2 -	—
	1 p.m.	-	-	SE b E 7·0	5·9 -	Ci.cu.st. 9	0 -	-	1·05 -	-	0·95 -	—
	4 p.m.	-	-	SE b E 7·1	6·8 -	Cir.cum. 4	0 -	-	1·0 -	-	0·9 -	—
	8 p.m.	-	-	ESE 6·5	5·8 -	- 6	0 -	-	0·8 -	-	0·7 -	—
	Midn.	-	-	ESE 9·7	5·4 -	Cum.str 10	0 -	-	0·3 -	-	0·2 -	—
Aug. 9	4 a.m.	-	-	ESE 6·9	6·0 -	10	0 -	-	0·7 -	-	0·6 -	—
	8 a.m.	-	-	SE 9·0	6·0 -	Strat. 10	0 -	-	2·4 -	-	2·3 -	—
	Noon.	-	-	NW b W 13·9	2·05 -	- 10	0 -	-	2·9 -	-	2·8 -	—
	3 p.m.	-	-	NW b W 10·3	2·7 -	Cum. 7	0 -	-	3·0 -	-	2·9 -	—
	4 p.m.	-	-	WNW 10·3	2·6 -	- 0·5	0 -	-	3·0 -	-	2·9 -	—
	8 p.m.	-	-	WNW 9·8	2·1 -	0 0·5	0 -	-	3·0 -	-	2·9 -	Scattered ice.
	Midn.	-	-	WNW 7·5	2·3 -	Strat. 10	0 -	-	2·0 -	-	1·9 -	No ice.
Aug. 10	4 a.m.			W 8·5	2·4 -	Fog 10	0 -	-	1·5 -	-	1·4 -	
	Noon.	70° 1′	65° 35′	SW b S 5·5	2·1 -	Strat. 9	0 -	-	0·7 -	-	0·6 -	Scattered ice.
	4 p.m.			SW b S 2·2	1·9 -	Cum.str. 9	0 -	-	1·0 -	-	0·9 -	—
	8 p.m.			WSW 4·7	1·7 -	- 6	0 -	-	0·1 -	-	0·0 -	—
	Midn.			WSW 2·8	1·3 -	Hazy str. 10	0 -	-	0·5 -	-	0·4 -	—
Aug. 11	4 a.m.			WSW 2·9	1·8 -	Fog 10	0 -	-	2·1 -	-	2·0 -	—
	8 a.m.			SW b S 2·7	0·95 -	- 10	0 -	-	1·0 -	-	0·9 -	—
	Noon.	71° 21′	66° 24′	WSW 2·8	0·45 -	- 10	0 -	-	0·05 -	-	— 0·05 -	Rather tight and big ice.
	4 p.m.			WSW 3·3	0·15 -	Light mist 10	0 -	-	2·0 -	-	1·9 -	Scattered ice.
	8 p.m.			WSW 2·6	2·05 -	Cum.str. 8	0 -	-	3·0 -	-	2·9 -	A few pieces of ice.
	Midn.			NE 3·3	2·6 -	Cum. 8	0 -	-	3·4 -	-	3·3 -	—
Aug. 12	4.30 a.m.			E 3·8	3·4 -	Cum.str. 8	0 -	-	3·0 -	-	2·9 -	Through a belt of scattered ice.
	8.45 a.m.			E b N 3·6	4·1 -	- 9	0 -	-	3·0 -	-	2·9 -	No ice.

Date. 1893.	Hour.	North Lat.	East Long.	Wind. Magn. Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Aug. 12	Noon.	72° 28′	68° 26′	E	4·4	+ 6·4° C.	Cum.str. 8	0 m.	Sbg. 25	3·4° C.	— 0.1	3·3° C.	No ice.
	4 p. m.			ENE	8·2	+ 5·2 -	- 10	0 -	-	3·4 -	-	3·3 -	A few solitary ice-floes.
	8 p. m.			NE b E	10·7	+ 4·9 -	- 9	0 -	-	3·5 -	-	3·4 -	No ice in sight.
	Midn.			NE b E	7·0	+ 5·2 -	Cum. 9	0 -	-	3·3 -	-	3·2 -	—
Aug. 13	4 a. m.			NE b E	8·7	+ 4·3 -	Cum.str. 9	0 -	-	4·0 -	-	3·9 -	—
	8 a. m.			NE b E	10·2	+ 4·5 -	- 9	0 -	-	3·0 -	-	2·9 -	—
	Noon.			ENE	8·8	+ 4·6 -	- 9	0 -	-	3·2 -	-	3·1 -	—
	4 p. m.	73° 34′	69° 50′	NE b E	10·0	+ 4·9 -	- 8	0 -	-	3·6 -	-	3·5 -	—
	8 p. m.			NE b E	10·2	+ 4·6 -	- 8	0 -	-	3·2 -	-	3·1 -	—
	Midn.			NE	8·4	+ 4·5 -	- 8	0 -	-	3·7 -	-	3·6 -	—
Aug. 14	4 a. m.			NE b E	7·8	+ 4·8 -	- 8	0 -	-	3·4 -	-	3·3 -	—
	8 a. m.			NE	8·1	+ 4·5 -	- 9	0 -	-	3·0 -	-	2·9 -	—
	Noon.	74° 29′	70° 15′	NE b E	7·8	+ 4·6 -	Strat. 10	0 -	-	3·2 -	-	3·1 -	—
	5.30 p. m.			NE b E	6·4	+ 4·7 -	Fog 10	0 -	-	3·1 -	-	3·0 -	—
	8 p. m.			NE b E	7·0	4·3 -	- 10	0 -	-	3·4 -	-	3·3 -	—
	Midn.			NE	4·4	4·5 -	- 10	0 -	-	3·0 -	-	2·9 -	No ice. The sea has a brownish colour.
Aug. 15	4 a. m.			ENE	1·9	4·1 -	- 10	0 -	-	4·0 -	-	3·9 -	No ice.
	8 a. m.	74° 38′	70° 57′	ESE	5·2	4·9 -	Cum.str. 9	0 -	-	4·3 -	-	4·2 -	—
	Noon.	74° 40′	71° 36′	NE b E	4·8	5·2 -	Hazy cir.cum. 3	0 -	-	5·0 -	-	4·9 -	—
	4 p. m.			NE b E	8·4	4·1 -	Fog 10	0 -	-	4·1 -	-	4·0 -	A few pieces of ice in sight.
	8 p. m.			ENE	8·0	4·0 -	Cum. 8	0 -	-	3·8 -	-	3·7 -	Solitary pieces of ice.
	Midn.			ENE	8·0	5·2 -	Strat. 9	0 -	-	3·0 -	-	2·9 -	—
Aug. 16	4 a. m.			E	9·6	5·2 -	- 7	0 -	-	4·0 -	-	3·9 -	A few belts of ice within sight.
	8 a. m.	74° 36′	75° 11′	ENE	11·8	4·9 -	Cum.str. 8	0 -	-	3·6 -	-	3·5 -	No ice.
	Noon.			NE b E	12·1	5·0 -	- 9	0 -	-	4·0 -	-	3·9 -	A few solitary pieces of ice.
	4 p. m.			ENE	13·0	3·7 -	Strat. 10	0 -	-	2·1 -	-	2·0 -	Scattered ice.
	8 p. m.			ENE	14·4	4·5 -	- 10	0 -	-	3·1 -	-	3·0 -	No ice.
	Midn.			ENE	12·6	4·6 -	- 10	0 -	-	2·5 -	-	2·4 -	Scattered ice.

Aug. 17	4 a.m.			ENE	12·9	2·3 -	-	10	0 -	-	1·5 -	-	1·4 -	Scattered ice.
	8·30 a.m.	75° 14′	78° 27′	ENE	14·8	2·8 -	Cum.str.	8	0 -	-	1·1 -	-	1·0 -	—
	Noon.	75° 24′		ENE	12·7	2·9 -	Cir.cum.	2	0 -	-	2·0 -	-	1·9 -	Rather big but scattered ice.
	4 p.m.	75° 15′	79° 42′	ENE	11·5	3·2 -	-	3	0 -	-	1·9 -	-	1·8 -	Scattered ice.
	8 p.m.			ENE	11·0	2·6 -	Cir.	2	0 -	-	2·0 -	-	1·9 -	Solitary pieces of ice.
	Midn.			ENE	10·8	2·4 -	-	3	0 -	-	1·25 -	-	1·15 -	Belts of ice.
Aug. 18	4 a.m.			ENE	10·1	2·8 -	0	1	0 -	-	1·5 -	-	1·4 -	Along the margin of tight ice.
	8 a.m.	74° 43′	80° 14′	ENE	14·4	2·5 -	Cir.	0	0 -	-	1·0 -	-	0·9 -	Among belts of ice.
	0.30 p.m.	74° 29′		ENE	14·4	3·4 -	-	0	0 -	-	2·1 -	-	2·0 -	Scattered, rather big floes
	4 p.m.	74° 3′	80° 38′	ENE	10·8	3·6 -	0	0	0 -	-	2·2 -	-	2·1 -	Only a few pieces of ice in sight.
	8 p.m.			ENE	10·3	3·8 -	0	0	0 -	-	1·6 -	-	1·5 -	No ice.
	Midn.	Dickson I. in sight		NE b E	11·1	3·3 -	Hazy	1	0 -	-	2·2 -	-	2·1 -	—
Aug. 19	4 a.m.			NE b E	11·1	1·8 -	-	0	0 -	-	0·7 -	-	0·6 -	—
	8 a.m.	73° 43′	81° 10′	NE	7·1	2·7 -	0	0	0 -	-	0·0 -	-	- 0·1 -	—
	Noon.	73° 55·6′		NE b E	10·0	2·3 -	0	0	0 -	-	0·2 -	-	0·1 -	—
	4 p.m.	74° 9′	82° 26′	ENE	9·3	5·3 -	0	0	0 -	-	0·1 -	-	0·0 -	—along edge of strong current running east.
	8 p.m.			NE b E	10·8	3·8 -	0	0	0 -	-	0·9 -	-	0·8 -	Solitary pieces of ice.
	Midn.			NE b E	9·1	4·8 -	0	0	0 -	-	3·1 -	-	3·0 -	No ice.
Aug. 20	4 a.m.	74° 54′	83° 39′	NE b E	7·6	2·6 -	0	0	0 -	-	1·0 -	-	0·9 -	Belts of small pieces of ice.
	8 a.m.			NE b E	7·3	3·2 -	0	0	0 -	-	1·4 -	-	1·3 -	Belts of ice in sight.
	Noon.	74° 59·5′		NE b E	6·2	4·8 -	0	0	0 -	-	3·3 -	-	3·2 -	No ice.
	4 p.m.	Off Kjellman Is.		N	5·4	4·3 -	0	0	0 -	-	3·2 -	-	3·1 -	Belts of ice in sight.
	8 p.m.	74° 49′	85° 42′	N	5·2	5·8 -	Cum.	2	0 -	-	2·8 -	-	2·7 -	At anchor among the Kjellman Islands.
	Midn.	-	-	NE	4·6	3·6 -	-	0	0 -	-	3·0 -	-	2·9 -	No ice.
Aug. 21	4 a.m.	-	-	NE	5·0	3·8 -	-	0	0 -	-	2·9 -	-	2·8 -	—
	8 a.m.	-	-	NE	8·8	2·55 -	-	3	0 -	-	2·75 -	-	2·65 -	—
	Noon.	74° 46′	85° 33′	NE	9·7	2·0 -	-	7	0 -	-	2·6 -	-	2·5 -	—Strong current running constantly south through the sound.
	6 p.m.	-	-	NE b N	12·2	1·8 -	Cir.cum.	3	0 -	-	1·5 -	-	1·4 -	— — —
	8 p.m.	-	-	NE	7·2	2·2 -		2	0 -	-	0·9 -	-	0·8 -	— — —
	Midn.	-	-	NE	9·0	1·5 -		10	0 -	-	1·2 -	-	1.1 -	— — —
Aug. 22	4 a.m.	-	-	NNE	10·4	— 0·3 -			0 -	-	2·2 -	-	2·1 -	— — —
	9 a.m.	-	-	N	8·0	0·6 -	Cum.	8	0 -	-	0·8 -	-	0·7 -	No ice (a little snow falling).
	Noon.	-	-	N b E	8·4	0·6 -	-	8	0 -	-	0·5 -	-	0·4 -	— — —
	8 p.m.	-	-	N b E	9.8	— 0·8 -	Fog	10	0 -	-	0·0 -	-	— 0·1 -	No ice. Strong current running south

Date. 1893.	Hour.	North Lat.	East Long.	Wind. Magn. Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Aug. 23	1 a. m.	74° 46′	85° 33′	N	11·2	— 0·8 °C.	Strat.	0 m.	Sbg. 25	— 0·5 °C.	— 0·1	— 0·6 °C.	No ice. Strong current running south.
	4 a. m.	-	-	N	8·6	— 0·2 -	- 10	0 -	-	— 0·9 -	-	— 1·0 -	— —
	8 a. m.	-	-	N b E	13.5	0·0 -	- 10	0 -	-	— 0·5 -	-	— 0·6 -	— —
	Noon.	-	-	NNE	11·8	— 1·0 -	- 10	0 -	-	— 0·8 -	-	— 0·9 -	— —
	4.30 p. m.	-	-	NNE	12·4	— 0·8 -	- 10	0 -	-	— 0·9 -	-	— 1·0 -	— —
	8 p. m.	-	-	NNE	13·6	— 0·9 -	- 10	1 -	-	— 1·0 -	-	— 1·1 -	— —
Aug. 24	4 a. m.	-	-	NNE	10·8	— 1·3 -	- 10	0 -	-	— 0·8 -	-	— 0·9 -	— —
	8 a. m.	-	-	NNE	10·2	— 0·6 -	Cum.str. 7	0 -	-	— 1·0 -	-	— 1·1 -	— —
	4 p. m.			NNE	10·2	0·0 -	- 9	0 -	-	— 0·7 -	-	— 0·8 -	— —
	8 p. m.			NNE	10·6	+ 0·2 -	Strat. 10	0 -	-	— 0·4 -	-	— 0·5 -	— —
	Midn.			NNE	10·8	1·2 -	Cum.str. 9	0 -	-	0·0 -	-	— 0·1 -	
Aug. 25	4 a. m.			NNE	9·7	— 0·2 -		0 -	-	— 0·9 -	-	— 1·0 -	
	8 a. m.			NE	10·7	+ 0·8 -	Cum.str. 9	0 -	-	— 0·8 -	-	— 0·9 -	— —
	Noon.			NNE	11·4	— 0·8 -	- 8	0 -	-	— 0·8 -	-	— 0·9 -	Belts of ice in sight.
	4 p. m.	75° 24′	85° 49′	NNE	10·0	— 0·2 -	Cir.cum. 2	0 -	-	— 0·3 -	-	— 0·4 -	No ice.
	8 p. m.			NE	9·0	— 0·4 -	Cum.str. 1	0 -	-	— 0·7 -	-	— 0·8 -	—
	Midn.			NE	8·5	— 0·8 -	- 1	0 -	-	— 0·8 -	-	— 0·9 -	Belts of ice in sight.
Aug. 26	4 a. m.			N	8·6	0·0 -	- 2	0 -	-	— 1·1 -	-	— 1·1 -	No ice.
	8 a. m.	75° 25′	87° 44′	N b E	7·5	— 0·95 -	Cir.cum. 4	0 -	-	— 1·1 -	-	— 1·2 -	—
	Noon.	75° 28′	88° 26′	NNE	9·8	— 1·3 -	Strat. 10	0 -	-	— 1·2 -	-	— 1·3 -	—
	4 p. m.	75° 39′	88° 36′	NNE	9·1	— 0·4 -	Cum.str. 7	0 -	-	— 0·9 -	-	— 1·0 -	—
	8 p. m.			N b E	7·7	— 1·0 -	Strat. 7	0 -	-	— 0·7 -	-	— 0·8 -	—
	Midn.			N b E	6·7	1·0 -	Cum.str. 8	0 -	-	— 1·0 -	-	— 1·1 -	—
Aug. 27	4 a. m.			N b E	3·7	— 1·6 -	Strat. 8	0 -	-	— 1·0 -	-	— 1·1 -	—
	8 a. m.	75° 57′	91° 19′	W b N	3·6	— 2·2 -	mist & cum 9	0 -	-	— 0·7 -	-	— 0·8 -	A few solitary belts of ice.
	Noon.	76° 6′	92° 17′	W b S	4·8	— 2·8 -	Fog. 9	0 -	-	— 0·8 -	-	— 0·9 -	No ice.
	4 p. m.			W b S	2·9	— 1·9 -	- 10	0 -	-	0·0 -	-	— 0·1 -	Scattered ice.
	8 p. m.			S W b S	3·4	— 2·1 -	- 8	0 -	-	— 0·5 -	-	— 0·6 -	
	Midn.			W	3·6	— 1·0 -	- 10	0 -	-	— 0·3 -	-	— 0·4 -	—

Aug. 28	4.30 a.m.			WNW	4·5	—1·2	-	Fog	10	0	-	-	—1·0	-	—1·1	-	Along the margin of the ice.
	8 a.m.			N	6·2	—0·95	-	Strat.	9	0	-	-	—0·5	-	—0·6	-	Scattered ice.
	Noon.	76° 46′	94° 32′	NNW	5·5	—0·4	-	-	9	0	-	-	—0·5	-	—0·6	-	—
	3.30 p.m.	76° 54′	95° 2′	NNW	3·5	0·0	-	Ci.cu.st.	3	0	-	-	—0·4	-	—0·5	-	Moored at the margin of the ice.
	8 p.m.			NW	3·7	—1·2	-	Cum.str.	6	0	-	-	—0·2	-	—0·3	-	— —
	Midn.			NNW	2·6	—1·2	-	-	7	0	-	-	—0·8	-	—0·9	-	Along the margin of the ice.
Aug. 29	4 a.m.			W	2·4	—0·9	-		10	0	-	-	—0·6	-	—0·7	-	Along the margin of the ice.
	8 a.m.			WSW	2·0	—0·8	-	Snowy sky	10	0	-	-	—0·5	-	—0·6	-	A little scattered ice.
	Noon.	76° 24′	94° 49′	SW		—0·35	-	Cum.	10	0	-	-	0·1	-	0·0	-	— —
	4 p.m.	Off Taimur Island.		SW	0	—0·06	-	Strat.	10	0	-	-	0·05	-	—0·05	-	
	8 p.m.	—	—	Calm.		—0·9	-	Ci.cu. & mist.	8	0	-	-	—0·3	-	—0·4	-	
	Midn.	Off C. Laptev		-		—0·8	-	Cum.str.	10	0	-	-	—0·4	-	—0·5	-	Moored to the ice.
Aug. 30	4 a.m.	—		-		—0·7	-			0	-	-	—0·2	-	—0·3	-	— —
	8 a.m.			-		—0·05	-	Strat.	10	0	-	-	0·0	-	—0·1	-	Open water.
	Noon.	C. Laptev		-		0·4	-	Cum.str.	10	0	-	-	0·1	-	0·0	-	Moored to the ice.
	4 p.m.	76° 25′	96° 27′	-		0·3	-	Strat.	10	0	-	-	0·0	-	—0·1	-	— —
	8 p.m.	-	-	-		—0·3	-	-	10	0	-	-	0·0	-	—0·1	-	— —
	Midn.	-	-	-		—0·3	-	Snowy sky	10	0	-	-	—0·25	-	—0·35		— —
Aug. 31	4 a.m.	-	-	-		—0·4	-	-	10	0	-	-	0·0	-	—0·1	-	— —
	8 a.m.	-	-	-		—0·1	-	-	10	0	-	-	—0·1	-	—0·2	-	— —
	Noon.	-	-	NW	3·8	—0·2	-	-	10	0	-	-	0·0	-	—0·1	-	Moored to the ice. Sea covered with a layer of melting snow.
	4 p.m.	-	-	NW	4·0	—0·05	-	-	10	0	-	-	0·0	-	—0·1	-	— —
	8 p.m.	-	-	NWbN	4·1	0·05	-	-	10	0	-	-	0·0	-	—0·1	-	— —
	Midn.	-	-	NNW	4·5	0·0	-	-	10	0	-	-	0·0	-	—0·1	-	— —
Sept. 1	4 a.m.	-	-	NNW	5·2	—0·4	-	-		0	-	-	—0·2	-	—0·3	-	— —
	8.30 a.m.	-	-	NbW	5·8	—0·22	-	-		0	-	-	0·0	-	—0·1	-	— —
	Noon.	-	-	NbW	4·1	0·0	-	-		0	-	-	0·0	-	—0·1	-	— —
	4 p.m.	-	-	NNW	2·9	—0·2	-	-	10	0	-	-	—0·1	-	—0·2	-	— —
	8 p.m.	-	-	NNW	4·1	—0·4	-	-	10	0	-	-	0·0	-	—0·1	-	— —
	Midn.	-	-	NNW	4·0	—0·2	-	-	10	0	-	-	—0·2	-	—0·3	-	— —

Date. 1893.	Hour.	North Lat.	East Long.	Wind. Magn. Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.		Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Sept. 2	4 a. m.	76° 25′	96° 27′	NNW	5·9	— 1·0 °C.	Snowy sky	10	0 m.	Sbg. 25	— 0·2 °C.	— 0·1	— 0·3 °C.	Moored to the ice. Sea covered with a layer of melting snow.
	8 a. m.	-	-	WbN	6·2	— 1·1 -	Clearing up	10	0 -	-	— 0·05 -	-	— 0·15 -	Moored to the ice. Surrounded by ice-floes.
	Noon.	-	-	W	5·2	— 1·05 -	Strat.	10	0 -	-	— 0·15 -	-	— 0·25 -	— —
	4 p. m.	-	.	WbS	5·0	— 1·0 -	Snowy sky	10	0 -	-	— 0·1 -	-	— 0·2 -	— —
	8 p. m.	-	-	W	5·6	— 2·4 -	Strat.	10	0 -	-	— 0·1 -	-	— 0·2 -	— —
	Midn.	Along Taimur I.		W	5·5	— 3·2 -	—	10	0 -	-	— 0·8 -	-	— 0·9 -	Scattered ice.
Sept. 3	4 a. m.	.	-	WSW	3·5	— 3·8 -	Fog	10	0 -	-	— 0·5 -	-	— 0·6 -	Solitary ice-floes.
	8 a. m.	-	-	S	4·8	— 2·5 -	Strat.	10	0 -	-	— 0·3 -	-	— 0·4 -	Newly formed ice-crust.
	Noon.	-	-	SW	5·0	— 1·15 -	Cir.cum.	2	0 -	-	— 0·3 -	-	— 0·4 -	No ice.
	4 p. m.	Archer Harbour		Calm.		— 0·6 -	Strat.	10	0 -	-	— 0·1 -	-	— 0·2 -	Scattered ice.
	8 p. m.	76° 12′	95°	SW	2·9	— 2·7 -	-	10	0 -	-	— 0·15 -	-	— 0·25 -	—
	9 p. m.	-	-	S					0 -	-	— 0·1 -	-	— 0·2 -	
	Midn.	-	-	SW	3·0	2·7 -	-	8	0 -	-	— 0·2 -	-	— 0·3 -	
Sept. 4	4 a. m.	-	-	N	2·0	— 4·2 -		8	0 -	-	— 0·6 -	-	— 0·7 -	
	8 a. m.	-	-	N	5·1	— 2·65 -	Snowy sky	10	0 -	-	— 0·3 -	-	— 0.4 -	—
	Noon.	-	-	NWbN	6·7	— 1·6 -	-	10	0 -	-	— 0·3 -	-	— 0·4 -	—
	4 p. m.	-	-	NW	4·6	— 0·8 -	Strat.	10	0 -	-	— 0·25 -	-	— 0·35 -	—
	9 p. m.	-	-	WbS	5·8	— 1·3 -	-	10	0 -	-	— 0·3 -	-	— 0·4 -	—
	Midn.	-	-	WSW	7·4	— 2·1 -	-	10	0 -	-	— 0·3 -	-	— 0·4 -	—
Sept. 5	4 a. m.	-	-	WSW	7·3	— 1·1 -	-	10	0 -	-	— 0·1 -	-	— 0·2 -	
	8 a. m.	-	-	WSW	12·9	— 1·0 -	-	10	0 -	-	— 0·65 -	-	— 0·75 -	No ice round the ship.
	Noon.	-	-	SW	17·0	— 2·5 -	-	10	0 -	-	— 1·1 -	-	— 1·2 -	No ice in the sound.
	4 p. m.	-	.	SW	13·6	— 2·35 -	-	10	0 .	-	— 1·1 -	-	— 1·2 -	— —
	8 p. m.	-	-	SWbS	16.0	— 2·1 -	-	10	0 -	-	— 1·15 -	-	— 1·25 -	— —
	Midn.	-	-	SWbS	12·6	— 1·2 -		10	0 -	-	— 0·2 -	-	— 0·3 -	— —
Sept. 6	4 a. m.	-	-	SWbS	13·0	— 2·4 -		10	0 -	-	— 1·2 -	-	— 1·3 -	— —
	8 a. m.	-	-	SSW	13·8	— 2·1 -	Cum.str.	9	0 -	-	— 1·2 -	-	— 1·3 -	— —
	Noon.	-	-	SbW	13·0	— 1·4 -	-	8	0 -	-	— 1·3 -	-	— 1·4 -	— —

	4 p. m.	76° 12′	95°	S	5·8	— 1·65 -	Cum.str. 6	0 -	-	— 1·35 -	-	— 1·45 -	No ice in the sound.
	8 p. m.			E	3·8	— 0·8 -	Strat. 10	0 -	-	— 0·7 -	-	— 0·8 -	Through scattered ice.
	Midn.			ESE	6·6	0·2 -	10	0 -	-	— 1·5 -	-	— 1·6 -	Solitary small pieces of ice.
Sept. 7	4 a. m.			SE b E	4·3	0·2 -	Cum.str. 8	0 -	-	— 1·3 -	-	— 1·4 -	— —
	8 a. m.			E b S	5·0	— 0·1 -	— 2	0 -	-	— 0·9 -	-	— 1·0 -	Much scattered ice.
	Noon.	76° 32′	98° 35′	ESE	3·2	1·4 -	Cum. 1	0 -	-	0·7 -	-	0·6 -	Through much ice.
	4 p. m.	76° 33′	99° 51′	E	6·0	0·9 -	Cum.str. 8	0 -	-	— 0·5 -	-	— 0·6 -	Tight ice to the north.
	8 p. m.			NE b E	6·2	0·75 -	Strat. 10	0 -	-	— 0·5 -	-	— 0·6 -	— —
	Midn.	76° 32′	100° 40′	E	4·0	1·2 -	Cum.str. 8	0 -	-	1·0 -	-	0·9 -	Moored to an ice-floe.
Sept. 8	4 a. m.	-	-	NNW	2.4	— 0·4 -	Cum.str. 8	0 -	-	— 0·8 -	-	— 0·9 -	— —
	8 a. m.	-	-	NNW	2·7	— 1·1 -	Strat. 2	0 -	-	0·8 -	-	0·7 -	— —
	Noon.	-	-	NNE	5·6	0·4 -	Cum.str. 8	0 -	-	— 0·3 -	-	— 0·4 -	— —
	4 p. m.	-	-	N b E	7·5	0·1 -	- 10	0 -	-	— 0·5 -	-	— 0·6 -	— —
	8 p. m.	-	-	NNE	6·5	0·3 -	Strat. 10	0 -	-	— 0·7 -	-	— 0·8 -	— —
	Midn.	-	-	NE b N	6·0	1·8 -	— 10	0 -	-	— 0·6 -	-	— 0·7 -	— —
Sept. 9	4 a. m.	-	-	E	4·4	3·8 -	Cum. 10	0 -	-	— 0·8 -	-	— 0·9 -	— —
	8 a. m.			ESE	9·7	4·5 -	Cum.str. 7	0 -	-	— 0·5 -	-	— 0·6 -	Scattered ice.
	Noon.	76° 56′		ESE	4·4	5·0 -	- 8	0 -	-	— 0·5 -	-	— 0·6 -	No ice near the ship.
	4 p. m.	77° 24′	101° 41′	SE	5·0	2·05 -	- 5	0 -	-	— 1·0 -	-	— 1·1 -	No ice.
	8 p. m.			SE b E	4·8	1·0 -	0 0	0 -	-	— 1·0 -	-	— 1·1 -	—
	Midn.			ESE	4·6	0·6 -	Strat. 0	0 -	-	0·0 -	-	— 0·1 -	Sea covered with a layer of melting crushed ice.
Sept. 10	4 a. m.	Off C. Chelyuskin		E b N	7·3	— 0·9 -	0 0	0 -	-	— 1·0 -	-	— 1·1 -	No ice.
	8 a. m.	77° 43′	105° 11′	E b S	6·3	— 0·2 -	Cum.str. 3	0 -	-	— 0·5 -	-	— 0·6 -	—
	Noon.	77° 36′	106° 3′	SSE	9·8	— 1·0 -	- 2	0 -	-	— 1·1 -	-	— 1·2 -	—
	4 p. m.			S b W	5·0	— 1·0 -	Snowy sky 10	0 -	-	— 1·0 -	-	— 1·1 -	Moored to the ice.
	8 p. m.			S b E	9·8	— 0·7 -	Strat. 10	0 -	-	— 1·0 -	-	— 1·1 -	Scattered ice.
	Midn.			SW	9·5	— 1·2 -	Snowy sky 10	0 -	-	— 1·2 -	-	— 1·3 -	Through belts of ice.
Sept. 11	4 a. m.			S	6·6	0·8 -		0 -	-	— 1·0 -	-	— 1·1 -	
	8 a. m.			SE	5·4	— 0·3 -	Cum.str. 9	0 -	-	— 0·7 -	-	— 0·8 -	No ice.
	Noon.	76° 58′	111° 32′	SE	5·8	— 0·5 -	- 9	0 -	-	— 1·1 -	-	— 1·2 -	Single ice-floes.
	4 p. m.			SE b E	6·2	— 0·8 -	- 9	0 -	-	— 1·1 -	-	— 1·2 -	Scattered ice.
	8 p. m.			SE b E	6·8	— 0·6 -	- 9	0 -	-	— 1·1 -	-	— 1·2 -	—
	Midn.					0·8 -	- 9	0 -	-	1·0 -	-	0·9 -	Rather tight ice.

Date. 1893.	Hour.	North Lat.	East Long.	Wind. Magn. Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Sept. 12	4 a.m.			Calm		—1·8 °C.	Strat. 9	0 m.	Sbg. 25	—1·5 °C.	—0·1	—1·6 °C.	
	8 a.m.			—		—0·6 -	Cum.str. 8	0 -	-	—1·45 -	-	—1·55 -	Scattered ice.
	Noon.	76° 2′	114° 12′	S	4.5	—0·8 -	— 7	0 -	-	—1·35 -	-	—1·45 -	Solitary ice-floes.
	4 p.m.			SE b S	2·6	—1·0 -	Cum. 7	0 -	-	—1·5 -	-	—1·6 -	Scattered ice.
	8 p.m.			Calm		—1·3 -	Cum.str. 7	0 -	-	—1·5 -	-	—1·6 -	—
	Midn.			E	5·3	—0·6 -	Strat. 10	0 -	-	—0·5 -	-	—0·6 -	Rather tight ice.
Sept. 13	4 a.m.			ENE	3·2	—0·2 -		0 -	-	—1·0 -	-	—1·1 -	
	8 a.m.			ENE	5·6	—0·05 -	Ci.cu.st. 7	0 -	-	—0·9 -	-	—1·0 -	— —
	Noon.	74° 55′	116°	NE b E	4·0	0·1 -	Cum.str. 10	0 -	-	—0·5 -	-	—0·6 -	— —
	4 p.m.			ENE	3·9	0·1 -	— 10	0 -	-	0·0 -	-	—0·1 -	Scattered ice.
	8 p.m.			NE	5·4	—0·3 -	— 10	0 -	Sbg. 107	—0·5 -	+ 0·1	—0·4 -	Solitary pieces of ice.
Sept. 14	4 a.m.	74° 25′	113° 56′	Calm		—1·0 -	Strat. 7	0 -	Sbg. 16	—0·8 -	0·0	—0·8 -	In the ice.
	8 a.m.			ENE	2·2	—0·6 -	Cum. 7	0 -	-	—0·5 -	-	—0·5 -	Scattered ice.
	Noon.			ESE	6·6	—1·2 -	Fog 10	0 -	-	—0·5 -	-	—0·5 -	—
	4 p.m.	73° 52′	114° 43′	E b N	8·0	0·55 -	Cum. 6	0 -	-	0·0 -	-	0·0 -	—
	8 p.m.			SE b E	8·5	0·75 -	- 9	0 -	-	0·05 -	-	0·05 -	No ice.
	Midn.			SE	7·4	0·27 -	Cum.str. 8	0 -	-	0·0 -	-	0·0 -	—
Sept. 15	4 a.m.			SE	10·6	—0·2 -	Strat.	0 -	-	—0·2 -	-	—0·2 -	—
	8 a.m.			E	9·7	—0·1 -	- 10	0 -	-	—0·1 -	-	—0·1 -	—
	Noon.	73° 54′	117° 0′	SW	6·9	0·4 -	- 10	0 -	-	—0·1 -	-	—0·1 -	Solitary pieces of ice.
	4 p.m.			SW	2·6	0·8 -	Ci.cu.st. 8	0 -	-	0·8 -	-	0·8 -	No ice.
	8 p.m.			WSW	3·8	0·8 -	Cum.str. 10	0 -	-	1·4 -	-	1·4 -	—
	Midn.			WSW	4·1	1·0 -	— 9	0 -	-	2·0 -	-	2·0 -	—
Sept. 16	4 a.m.			WSW	4·8	0·8 -	- 9	0 -	-	1·8 -	-	1·8 -	—
	8 a.m.	74° 20′	121° 20′	WSW	4·1	0·9 -	- 9	0 -	-	1·9 -	-	1·9 -	—
	Noon.	74° 26′	122° 9′	SSW	3·8	1·0 -	- 9	0 -	-	1·55 -	-	1·55 -	—
	4 p.m.			SSW	4·2	—0·2 -	Strat. 10	0 -	-	0·9 -	-	0·9 -	—
	8 p.m.			SSW	0	0·2 -	Cum.str. 9	0 -	-	1·0 -	-	1·0 -	—
	Midn.			WNW	6·4	—0·2 -	Strat. 9	0 -	-	0·6 -	-	0·6 -	—

Sept. 17	4 a. m.			WNW	6·4	— 0·1 -	Cum.str.	9	0 -	-	0·6 -	-	0·6 -	Ice within view.
	8 a. m.	74° 52′	128° 45′	WNW	7·1	— 0·4 -	-	9	0 -	-	— 0·05 -	-	— 0·05 -	Through some scattered pieces of ice.
	Noon.	75° 1′	129° 49′	W	8·0	— 0·8 -	-	6	0 -	-	— 0·35 -	-	— 0·35 -	No ice.
	4 p. m.			SW	3·7	0·0 -	-	7	0 -	-	— 0·35 -	-	— 0·35 -	
	8 p. m.			SW	5·0	— 0·3 -	Strat.	10	0 -	-	— 0·4 -	-	— 0·4 -	Near the ice.
	Midn.			SW	4·5	0·0 -	Cum.	10	0 -	-	0·4 -	-	0·4 -	No ice.
Sept. 18	4 a. m.			SW	4·3	0·3 -	Strat.	10	0 -	-	0·4 -	-	0·4 -	—
	8 a. m.			W	5·0	0·55 -	-	10	0 -	-	— 0·08 -	-	— 0·08 -	—
	0.30 p. m.			W b N	9·2	— 0·8 -	Mist	5	0 -	-	— 0·15 -	-	— 0·15 -	—
	4 p. m.	74° 50′	134° 24′	WNW	5·4	— 0·5 -	Cum.str.	9	0 -	-	— 0·65 -	-	— 0·65 -	—
	8 p. m.	75° 10′	135° 15′	W	6·2	— 0·6 -	-	8	0 -	-	— 0·5 -	-	— 0·5 -	—
	Midn.			WSW	4·2	— 0·6 -	-	10	0 -	-	— 0·81 -	-	— 0·81 -	—
Sept. 19	4 a. m.			SW	5·3	— 1·4 -	Cum.	10	0 -	-	— 0·5 -	-	— 0·5 -	—
	8 a. m.			S b E	7·2	— 0·6 -	Fog	10	0 -	-	— 0·65 -	-	— 0·65 -	—
	Noon.	76° 4′	134° 38′	SSE	4·8	0·45 -	Cum.str.	10	0 -	-	— 0·7 -	-	— 0·7 -	—
	4 p. m.	76° 19′	135° 9′	SSE	5·7	0·35 -	Strat.	10	0 -	-	— 0·6 -	-	— 0·6 -	A few small pieces of ice.
	8 p. m.			SSE	5·4	0·2 -	-	10	0 -	-	— 0·6 -	-	— 0·6 -	No ice.
	Midn.			S	5·5	1·4 -	-	10	0 -	-	— 0·4 -	-	— 0·4 -	
Sept. 20	4 a. m.			S	4·6	1·4 -	Cum.str.	7	0 -	-	— 0·5 -	-	— 0·5 -	
	8 a. m.			S	5·9	— 0·42 -	Fog	10	0 -	-	— 0·95 -	-	— 0·95 -	No ice.
	Noon.	77° 46·5′		S	7·0	— 0·4 -	-	10	0 -	-	— 1·4 -	-	— 1·4 -	Along the margin of the pack-ice.
	4.30 p. m.	77° 51′	137° 15′	S	4·2	— 0·42 -	Cum.str.	7	0 -	-	— 1·4 -	-	— 1·4 -	— —
	8 p. m.			SW	2·7	— 1·2 -	Fog	10	0 -	-	— 1·4 -	-	— 1·4 -	— —
	Midn.			SSW	3·2	— 1·76 -	-	10	0 -	-	— 1·5 -	-	— 1·5 -	— —
Sept. 21	4 a. m.			S	2·6	— 1·0 -	-	10	0 -	-	— 1·2 -	-	— 1·2 -	— —
	8 a. m.			SE b S	5·2	— 1·76 -	-	10	0 -	-	— 1·6 -	-	— 1·6 -	— —
	Noon.			SE	7·8	— 2·9 -	Strat. & mist	10	0 -	-	— 1·8 -	-	— 1·8 -	Much crushed ice on the sea-surface.
	4 p. m.			SE	5·4	— 2·2 -	Fog	10	0 -	-	— 1·7 -	-	— 1·7 -	— —
	8 p. m.	78° 40′	133° 8′	SE	8·5	— 1·1 -	Strat.	10	0 -	-	— 1·7 -	-	— 1·7 -	Near belt of ice.
	Midn.			SE	7·6	— 0·9 -	-	10	0 -	-	— 1·7 -	-	— 1·7 -	

[1] The error of Söderberg No. 16 in October, 1893, was determined to be — 0·05° C. According to this, the error would probably have been about — 0·04° C. in September, 1893, but as temperatures are only read to 0·1° C., I think it better to leave this error out of consideration.

Date. 1893.	Hour.	North Lat.	East Long.	Wind. True[1] Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.		Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Sept. 22	4 a. m.			SE	9·2	— 0·6 °C.	Strat.	2	0 m.	Sbg. 16	— 1·6° C.	0·0	— 1·6° C.	At the margin of the pack-ice.
	8 a. m.	78° 49′	132° 52′	SE	7·8	— 0·4 -	Cum.	2	0 -	-	— 1·7 -	-	— 1·7 -	— —
	0.30 p. m.	78° 51′		SE	9·2	— 0·7 -	0	0	0 -	-	— 1·7 -	-	— 1·7 -	— — much crushed ice.
	5.30 p. m.	78° 42′	133° 35′	ESE	6·6	— 2·7 -	0	0	0 -	-	— 1·7 -	-	— 1·7 -	Moored to an ice-floe. Scattered ice.
	8 p. m.			E	6·2	— 3·25 -	0	0	0 -	-	— 1·7 -	-	— 1·7 -	The ice tighter.
	Midn.			ENE	5·9	— 3·3 -	Cum.	10	0 -	-	— 1·8 -	-	— 1·8 -	— —
Sept. 23	4 a. m.			E	6·0	— 3·0 -	-		0 -	-	— 1·8 -	-	— 1·8 -	— —
	8 a. m.			ESE	6·1	— 2·7 -	Strat.	10	0 -	-	— 1·75 -	-	— 1·75 -	— —
	Noon.			EbS	5·6	— 1·7 -	Fog	10	0 -	-	— 1·7 -	-	— 1·7 -	— —
	4·30 p. m.			ESE	6·2	— 1·0 -	-	10	0 -	-	— 1·7 -	-	— 1·7 -	The ice still tighter.
	8·30 p. m.			ESE	6·4	— 1·3 -	-	10	0 -	-	— 1·7 -	-	— 1·7 -	— —
	Midn.			ESE	5·1	— 0·8 -	Strat.	10	0 -	-	— 1·7 -	-	— 1·7 -	— —
Sept. 24	4 a. m.			ESE	4·4	— 1·1 -	Fog	10	0 -	-	— 1·65 -	-	— 1·65 -	— —
	8 a. m.			SE	4·7	— 1·8 -	-	10	0 -	-	— 1·6 -	-	— 1·6 .	— —
	0.30 p. m.	78° 51′		EbS	3·5	— 2·4 -	0	0	0 -	-	— 1·8 -	-	— 1·8 -	Entirely enclosed by ice.
	5 p. m.			NNE	3·0	— 4·9 -	0	0	0 -	-	— 1·75 -	-	— 1·75 -	
	8.20 p. m.			E	3·9	— 5·6 -	0	0	0 -	-	— 1·7 -	-	— 1·7 -	
	Midn.		132° 22′	E	2·0	— 2·2 -	0	0	0 -	-	— 1·7 -	-	— 1·7 -	
Sept. 25	4 a. m.			E	1·4	— 6·8 -	0	0	0 -	-	— 1·8 -	-	— 1·8 -	
	8 a. m.			NEbE	2·7	— 7·4 -	frosty mist	10	0 -	-	— 1·75 -	-	— 1·75 -	
	1 p. m.			EbS	3·3	— 4·8 -	Strat.	10	0 -	-	— 1·7 -	-	— 1·7 -	
	4 p. m.			E	4·2	— 6·0 -	Cum.str.	9	0 -	-	— 1·7 -	-	— 1·7 -	
	8 p. m.			EbS	4·2	— 6·6 -	Cum.	9	0 -	-	— 1·8 -	-	— 1·8 -	
	Midn.			SE	3·1	— 4·8 -	Strat.	10	0 -	-	— 1·8 -	-	— 1·8 -	
Sept. 26	4 a. m.			EbS	3·4	— 4·4 -	Cum.str.	9	0 -	-	— 1·8 -	-	— 1·8 -	
	8 a. m.			Calm		— 4·96 -	Cum.	9	0 -	-	— 1·8 -	-	— 1·8 -	
	Noon.	78° 50′	132° 10′	NEbE	2·2	— 5·8 -	Cum.str.	4	0 -	-	— 1·7 -	-	— 1·7 -	
Sept. 27	Noon.			SSE	6·4	— 1·8 -	-	10	0 -	-	— 1·8 -	-	— 1·8 -	

Sept. 28	1 p. m.			SWbS 9·0	— 0·8 -	Strat. 7	0 -	-	— 1·7 -	-	— 1·7 -	
Sept. 29	Noon.	79° 4′		SW 3·3	— 3·3 -	Cum.str. 7	0 -	-	— 1·8 -	-	— 1·8 -	
Sept. 30	Noon.			NNW 3·5	— 3·95 -	- 10	0 -	-	— 1·8 -	-	— 1·8 -	
Oct. 1	Noon.			SWbW 10.2	— 1·15 -	Strat. 10	0 -	-	— 1·8 -	-	— 1·8 -	
Oct. 2	Noon.	78° 52′	134° 57′	WbS 9·2	— 1·5 -	- 10	0 -	-	— 1·75 -	-	— 1·75 -	
Oct. 4	Noon.	78° 38′		WbN 7·5	— 12·0 -	- 10	0 -	-	— 1·7 -	-	— 1·7 -	
Oct. 8	Noon.	78° 22′	136° 5′	N 5·8	— 16·4 -	Cum.str. 8	0 -	-	— 1·6 -	-	— 1·6 -	
Oct. 9	3 p. m.			NbE 4·2	— 15·05 -	- 8	0 -	-	— 1·6 -	-	— 1·6 -	
Oct. 11	Noon.			NbW 7·2	— 19·8 -	0 0	0 -	-	— 1·6 -	-	— 1·6 -	
Oct. 12	Noon.	78° 13′	135° 57′	NWbN 5·5	— 17·4 -	0 0	0 -	-	— 1·6 -	-	— 1·6 -	
Oct. 14	Noon.			SbE 2·9	— 20·4 -	Strat. 10	0 -	-	— 1·75 -	-	— 1·75 -	
Oct. 17	Noon.	78° 19′	136° 15′	SWbW 2·9	— 13·7 -	- 10	0 -	-	— 0·8? -	-	— 0·8? -	
Oct. 19	4 p. m.	78° 19·5′	136° 17′	NEbE 2·8	— 20·5 -	- 10	0 -	-	— 1·6 -	-	— 1·6 -	
Oct. 20	Noon.			NbE 5·1	— 19·4 -	- 10	0 -	-	— 1·6 -	-	— 1·6 -	
Oct. 21	Noon.			NbE 3·7	— 19·0 -	- 10	0 -	-	— 1·6 -	-	— 1·6 -	
Oct. 22	4 p. m.			Calm	— 21·0 -	Cum. 9	0 -	-	— 1·7 -	-	— 1·7 -	
Oct. 23	4 p. m.	78° 17′	135° 27′	ENE 1·9		-	0 -	-	— 1·5 -	-	— 1·5 -	
Oct. 24	Noon.			SEbE 1·6	— 26·0 -	0 0	0 -	-	— 1·55 -	-	— 1·55 -	
Oct. 25	Noon.			SWbS 6·9	— 16·85 -	Strat. 10	0 -	Sbg. 107	— 1·55 -	+ 0·1	— 1·45 -	
Oct. 26	Noon.	78° 32′	136° 12′	SbE 4·4	— 20·9 -	Cum. 1	0 -	-	— 1·6 -	-	— 1·5 -	
Oct. 27	Noon.			NbE 5·5	— 19·4 -	0 0	0 -	-	— 1·78 -	-	— 1·68 -	
Oct. 28	Noon.	78° 20′	135° 46′	NE 3·6	— 23·2 -	Strat. snowy sky 10	0 -	-	— 1·6 -	-	— 1·5 -	
Oct. 29	Noon.			NWbW 6·7	— 21·0 .	Hazy 10	0 -	-	— 1·6 -	-	— 1·5 -	
Oct. 30	Noon.	78° 13·5′	135° 28′	NbE 5·2	— 27·8 -	0 0	0 -	-	— 1·5 -	-	— 1·4 -	

[1] Until Oct. 1st, the direction indicated is magnetic; see page 65.

Date. 1893.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds		Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Oct. 31	Noon.			N b W	7·7	— 26·0° C.	0	0	0 m.	Sbg. 107	— 1·6° C.	+ 0·1	— 1 50° C.	
Nov. 1	Noon.	78° 3′	134° 51′	N b E	4·5	— 25·2 -	Strat.	8	0 -	-	— 1·5 -	-	— 1·40 -	
Nov. 2	Noon.			N b E	3·5	— 30·8 -	0	0	0 -	-	— 1·55 -	-	— 1·45 -	
Nov. 3	Noon.	78° 1′	134° 57′	Calm		— 33·6 -	0	0	0 -	-	— 1·6 -	-	— 1·50 -	
Nov. 4	Noon.			W b N	4·0	— 20·6 -	0	0	0 -	-	— 1·6 -	-	— 1·50 -	
Nov. 5	1 p. m.			W b S	7·2	— 20·8 -	Cum.str.	10	0 -	-	— 1·55 -	-	— 1·45 -	
Nov. 6	Noon.			WSW	11·8	— 19·3 -	Strat.	10	0 -	-	— 1·6 -	-	— 1·50 -	
Nov. 7	Noon.	77°50′	137° 55′	W	16·2	— 6·4 -	-	10	0 -	-	— 1·6 -	-	— 1·50 -	
Nov. 8	Noon.			N b E	2·2	— 31·2 -	0	0	0 -	-	— 1·65 -	-	— 1·55 -	
Nov. 9	Noon.			SE b E	5·7	— 21·1 -	0	0	0 -	-	— 1·6 -	-	— 1·50 -	
Nov. 10	Noon.	77°57′	137° 49′	SW b W	3·8	— 20·0 -	0	0	0 -	-	— 1·75 -	-	— 1·65 -	
Nov. 11	Noon.			S b W	4·2	— 15·15 -	Strat.	10	0 -	-	— 1·6 -	-	— 1·50	
Nov. 12	Noon.			SSW	10·4	— 18·6 -	-	10	0 -	-	— 1·65 -	-	— 1·55 -	
Nov. 13	Noon.	78° 2′	138° 25′	W b N	4·2	— 23·1 -	0	0	0 -	-	— 1·65 -	-	— 1·55 -	
Nov. 14	Noon.			SW b S	4·0	— 25·65 -	0	0	0 -	-	— 1·7 -	-	— 1·60 -	
Nov. 15	Noon.			S b E	9·0	— 20·6 -	0	0	0 -	-	— 1·65 -	-	— 1·55 -	
Nov. 16	Noon.	78°19′	139° 0′	SE b S		— 17·9 -	Hazy snowy sky	10	0 -	-	— 1·75 -	-	— 1·65 -	
Nov. 18	Noon.			SE b S	1·5	— 30·0 -	0	0	0 -	-	— 1·7 -	-	— 1·60 -	
Nov. 19	Noon.			N b W	1·9	— 29·9 -	0	0	0 -	-	— 1·8 -	-	— 1·70 -	
Nov. 20	Noon.	78°24′	139° 18′	N b W	4·1	— 26·0 -	Strat.	10	0 -	-	— 1·75 -	-	— 1·65 -	
Nov. 22	Noon.	78°26′	139° 24′	S b E	4·8	— 29·1 -	0	0	0 -	-	— 1·75 -	-	— 1·65 -	

Nov. 28	Noon.	78°39′	138° 54′	SE b E	2·2	— 26·7 -	Cum.str. 8	0 -	Sbg. 22	— 1·45 -	— 0·1	— 1·55 -	
Nov. 29	Noon.			S b E	2·2	— 30·0 -	0 0	0 -	-	— 1·4 -	-	— 1·5 -	
Nov. 30	11 a. m.			S b E	2·5	— 23·0 -	Strat. 10	0 -	Sbg. 105	— 1·8 -	+ 0·11	— 1·69 -	
Dec. 1	Noon.	78°42′	138° 36′	S b E	2·4	— 17·0 -	- 10	0 -	Sbg. 111	— 1·8 -	+ 0·08	— 1·72 -	
Dec. 3	10 a. m.	78°45′	138° 21′	SE b S	3·1	— 29·3 -	0 0	0 -	-	— 1·7 -	-	— 1·62 -	
Dec. 5	Noon.	78°51′	137° 50′	SE b E	4·8	— 34·8 -	Strat. 10	0 -	-	— 1·75 -	-	— 1·67 -	
Dec. 6	11 a. m.			SE b E	4·1	— 34·2 -	0 0	0 -	-	— 1·7 -	-	— 1·62 -	
Dec. 7	Noon.			SE b E	3·3	— 29·2 -	0 0	0 -	-	— 1·7 -	-	— 1·62 -	
Dec. 8	Noon.	78°56′	137° 37′	S b E	2·6	— 34·8 -	0 0	0 -	-	— 1·7 -	-	— 1·62 -	
Dec. 20	Noon.	79° 7	137° 27′	E b S	1·4	— 32·7 -	0 0	0 -	-	— 1·8 -	-	— 1·72 -	
Dec. 21	Noon.	79° 7′	137° 20′	E b N	0	— 29·7 -	Hazy 10	0 -	Sbg. 105	— 1·6 -	+ 0·11	— 1·49 -	
	1 p. m.			E b N	0	— 28·2 -	- 10	0 -	-	— 1·6 -	-	— 1·49 -	
1894													
Jan. 23	11 a. m.	79°42′	135° 33′	E b S	3·4	— 33·1 -	0 0	0 -	-	— 1·75 -	+ 0·13	— 1·62 -	
Jan. 28	Noon.	79°45′	134° 44′	SE b E	2·3	— 37·5 -	0 0	0 -	-	— 1·7 -	-	— 1·57 -	
Jan. 29	3 p. m.	79°45′	134° 44′	E b S	1·9	— 40·0 -	0 0	0 -	Müll. 7	— 1·5 -	— 0·05	— 1·55 -	By the same thermometer, the freezing-point of the water was determined to be — 1·55° C. = 1·60° C.
Febr. 1	3 p. m.	79°55′	134° 22′	S b E	5·0	— 19·6 -	Strat. 10	0 -	-	— 1·53 -	-	— 1·58 -	
Febr. 3	Noon.	79°59′	134° 21′	WSW	2·8	— 40·0 -	0 0	0 -	-	— 1·55 -	-	— 1·60 -	
Febr. 5	Noon.	79°57′	134° 38′	WSW	1·9	— 46·8 -	0 0	0 -	-	— 1·55 -	-	— 1·60 -	
Febr. 14	11 a. m.	80° 0′	133° 59′	N	1·9	— 36·8 -	Hazy 10	0 -	-	— 1·55 -	-	— 1·60 -	
Febr. 16	Noon.	80° 3′		N b E	0	— 44·5 -	0 0	0 -	-	— 1·55 -	-	— 1·60 -	
Febr. 19	Noon.	80° 3′	133° 55′	S b W	3·9	— 43·2 -	0 0	0 -	-	— 1·55 -	-	— 1·60 -	
Febr. 21	11 a. m.	80° 7′	133° 54′	S b E	6·3	— 25·35 -	Strat. 10	0 -	Sbg. 105	— 1·8 -	+ 0·15	— 1·65 -	

Date. 1894.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Febr. 24	11 a. m.	80° 6′	134° 2′	SW b W	2·1	— 37·8° C.	0 0	0 m.	Müll. 7	— 1·55° C.	— 0·05	— 1·60° C.	
Febr. 28	11 a. m.			W b N	1·3	— 26·5 -	Cum cir 10	0 -	-	— 1·6 -	-	— 1·65 -	
March 5	Noon.	79° 54′	134° 46′	NW	3·6	— 40·1 -	Hazy 10	0 -	-	— 1·6 -	-	— 1·65 -	
March 8	Noon.	79° 43′	134° 17′	W b N	3·0	— 40·1 -	Cir.cum. 10	0 -	-	— 1·6 -	-	— 1·65 -	
March 12	Noon.	79° 41′	134° 14′	NE b N	4·3	— 48·0 -	0 0	0 -	-	— 1·55 -	-	— 1·60 -	
March 15	11 a. m.	79° 39′	135° 0′	W b N	2·2	— 40·9 -	0 0	0 -	-	— 1·55 -	— 0·06	— 1·61 -	
March 19	11 a. m.	79° 39′	135° 12′	SW b W	5·2	— 43·0 -	0 0	0 -	-	— 1·54 -	-	— 1·60 -	
March 24	11 a. m.	80° 1′	134° 43′	S b E	3·0	— 35·1 -	0 0	0 -	-	— 1·55 -	-	— 1·61 -	
March 30	11 a. m.	80° 9′		SSW	8·4	— 25·3 -	Snowy air Cum.cir. 10	0 -	-	— 1·55 -	-	— 1·61 -	
Apr. 3	11 a. m.	80° 9′	134° 57′	WNW	3·5	— 35·0 -	0 0	0 -	-	— 1·57 -	-	— 1·63 -	
Apr. 10	11 a. m.	80° 17′		ENE	4·1	— 22·1 -	Hazy 3	0 -	-	— 1·57 -	-	1·63 -	
Apr. 16	11 a. m.	80° 16′	133° 10′	ESE	9·3	— 13·6 -	Snow Cum.str. 8	0 -	-	— 1·55 -	-	— 1·61 -	
Apr. 19	11 a. m.	80° 27′	131° 49′	SE	4·4	— 13·3 -	Cum.str. 10	0 -	Sbg. 105	— 1·75 -	+ 0·13	— 1·62 -	
May 25	8 p. m.	81° 31′	123° 8′	E b N	5·9	— 4·6 -	Strat. 10	0 -	Sbg. 114	— 1·63 -	+ 0·05	— 1·58 -	
May 30	Noon.	81° 33′	122° 22′	NE b N	6·0	— 4·5 -	- 10	0 -	-	— 1·63 -	-	— 1·58 -	
June 5	10 p. m.	81° 29′	122° 12′	W b N	3·3	— 6·0 -	Cir.cum. 4	0 -	-	— 1·63 -	-	— 1·58 -	
June 9	4.20 p. m.	81° 32′	122° 6′	S	3·8	— 2·1 -	Str. Fine ice-crystals in the air 10	0 -	-	0·1 -	-	0·15 -	In the water-hole.
	9 p. m.			SE	4·8	— 3·3 -	Cum. 10	0·01 -	-	0·0 -	-	0·05 -	Close under the thin ice-crust covering the water-surface.
								0·03 -	-	0·75 -	-	0·80 -	
								0·30 -	-	0·1 -	-	0·15 -	
								2 -	-	— 1·53 -	-	— 1·48 -	Water-sample taken with bucket.

June 14	5 p. m.	81° 48′	122° 5′	S b E	5·0	0·9 -	Str.	10	3 -	-	— 1·1 -	-	— 1·05 -	Sample taken with bucket.
	-								3 -	-	— 1·05 -	-	— 1·0 -	— —
June 18	11 a. m.	81°52′	121° 31′	SE	1·0	1·1 -	Cir.str.	10	3 -	-	— 1·6 -	-	— 1·55 -	Water-sample taken with bucket, which had been hanging in the sea at a depth of 3 m. since midnight.
June 23	9 p. m.	81° 43′	121° 21′	NE b N	5·8	— 0·05 -	Str. Sleet	10	3 -	-	— 1·5 -	-	— 1·45 -	
June 27	11 a. m.	81° 35′	121° 12′	SW b W	6·7	0·3 -	Cum.str. Heavy sleet	10	0 -	-	0·45 -	-	0·50 -	
									2 -	-	— 0·15 -	-	— 0·10 -	Water-samples taken with glass bottle.
									2 -	-	— 0·15 -	-	— 0·10 -	
	10·20 p. m.	81° 35′	121° 12′	SW	5·6	0·3 -	0	0	0 -	-	0·4 -	-	0·45 -	
									3 -	-	— 1·5 -	-	— 1·45 -	Water-sample taken with bucket.
									0 -	-	0·4 -	-	0·45 -	In a dirty (brownish) pond on the ice, communicating with the sea in the water-hole.
									0 -	-	0·25 -	-	0·30 -	In a closed pure fresh-water pond on the ice.
July 3	Noon.	81° 35′	123° 28′	SW b S	4·2	1·3 -	Str.	10	0 -	-	0·4 -	-	0·45 -	In pond on the ice.
									0 -	-	— 0·08 -	-	— 0·03 -	In an open lane.
									0 -	-	0·13 -	-	0.18 -	In same between some pieces of ice.
									0 -	-	0·2 -	-	0·25 -	In the water-hole.
									1 -	-	0·06 -	-	0·11 -	
									2 -	-	0·05 -	-	0·10 -	
									3 -	-	— 1·6 -	-	— 1·55 -	
July 7	2 p. m.	81° 26′	124° 35′	NW	6·5	0·8 -	Cum.str.	10	0 -	-	0·25 -	-	0·30 -	
									1 -	-	0·0 -	-	0·05 -	
									2 -	-	— 0·05 -	-	0·00 -	
									2·5 -	-	— 0·12 -	-	— 0·07 -	
									3 -	-	— 1·62 -	-	— 1·57 -	

Date. 1894.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
July 9	3 p. m.	81° 19′	124° 31′	W b N	4·0	0·15° C.	Cir.str. 10 Fog above the ice.	0 m.	Sbg. 114	0·42° C.	+ 0·05	0·47° C.	
								1 -	-	0·35 -	-	0·40 -	
								2 -	-	0·28 -	-	0·33 -	
								2·5 -	-	— 0·03 -	-	0·02 -	
								2·6 -	-	— 0·1 -	-	— 0·05 -	
								2·7 -	-	— 0·3 -	-	— 0·25 -	
								2·8 -	-	— 1·52 -	-	— 1·47 -	
								2·9 -	-	— 1·60 -	-	— 1·55 -	
								3·0 -	-	— 1·58 -	-	— 1·53 -	
								3·0 -	-	— 1·59 -	-	— 1·54 -	
								3·1 -	-	— 1·58 -	-	— 1·53 -	
July 10	8 a. m.	81° 18′	124° 35′	W b N	2·5	— 0·6 -	Cir.cum. 9 Cir.str. Light mist						Thin crust of ice formed during the night on all the small pools on the floes, but not on the larger ponds.
July 17	3 p. m.	81° 26′	125° 12′	NW b N	3·7	— 0·1 -	Str. Cir.str. 10	0 -	-	0·28 -	-	0·33 -	In a new water-hole which communicated with several ponds on the surrounding ice.
								1 -	-	0·1 -	-	0·15 -	
								1·5 -	-	0·13 -	-	0·18 -	
								2 -					At this depth an ice-layer had formed, and the temperature observations below 2 m. had therefore to be made in the old water-hole.
								2 -	-	0·14 -	-	0·19 -	In the old water-hole.
								2·3 -	-	— 0·19 -	-	— 0·14 -	
								2·5 -	-	— 0·92 -	-	— 0·87 -	
								2·8 -	-	— 1·51 -	-	— 1·46 -	

								3 -	-	— 1·50 -	-	— 1·45 -	
								3·1 -	-	— 1·48 -	-	— 1·43 -	
July 21	3 p. m.	81° 31·5′	125° 5′	N b E 4·5	— 0·3 -	Str. 10		0 -	-	0·28 -	-	0·33 -	
								1 -	-	0·30 -	-	0·35 -	
								1·8 -	-	0·10 -	-	0·15 -	
								1·9 -	-	— 0·10 -	-	— 0·05 -	
								2·0 -	-	— 0·28 -	-	— 0·23 -	
								2·1 -	-	— 0·52 -	-	— 0·47 -	
								2·25 -	-	— 1·50 -	-	— 1·45 -	
								2·5 -	-	— 1·54 -	-	— 1·49 -	
								3·0 -	-	— 1·50 -	-	— 1·45 -	
July 24	3 p. m.	81° 24′	125° 22′	WSW 6·0	0·1 -	Str. 10		0 -	-	0·28 -	-	0·33 -	
								1 -	-	0·28 -	-	0·33 -	
								1 -	-	0·28 -	-	0·33 -	
								1·6 -	-	0·15 -	-	0·20 -	
								1·7 -	-	— 0·3 -	-	0·25 -	
								1·8 -	-	— 0·18 -	-	— 0·13 -	
								1·9 -	-	— 0·40 -	-	— 0·35 -	
								2 -	-	— 0·80 -	-	— 0·75 -	
								2·1 -	-	— 1·4 -	-	— 1·35 -	
								2·25 -	-	— 1·45 -	-	— 1·40 -	
								2·5 -	-	— 1·45 -	-	— 1·40 -	
								2·8 -	-	— 1·48 -	-	— 1·43 -	
								3·0 -	-	— 1·50 -	-	— 1·45 -	
July 27	a. m.	81° 14′	125° 40′	NW b N 5·3	0·3 -	Str. 10		0 -	-	0·25 -	-	0·30 -	In a fresh-water pond on the ice.
								0 -	-	0·16 -	-	0·21 -	In an open lane.
								1·0 -	-	0·14 -	-	0·19 -	
								1·2 -	-	0·11 -	-	0·16 -	
								1·4 -	-	0·11 -	-	0·16 -	
								1·5 -	-	0·02 -	-	0·07 -	
								1·6 -	-	— 0·31 -	-	— 0·26 -	
								2·0 -	-	— 1·53 -	-	— 1·48 -	
								3·0 -	-	— 1·55 -	-	— 1·50 -	

Date. 1894.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
July 30	p. m.	81° 3·5′	126° 2′	WNW	4·4	0·5° C[1]	Cir.str. 10 Fine, misty rain	0 m.	Sbg. 114	0·38° C.	+ 0·05	0·43° C.	In the water-hole at the kennels near the 'Fram'.
								1 -	-	0·58 -	-	0·63 -	
								1 -	-	0·58 -	-	0·63 -	
								1·6 -	-	0·15 -	-	0·20 -	
								1·7 -	-	0·0 -	-	0·05 -	At a depth of about 1·6 m. there was a layer of ice, which was, however, easily broken through by the glass bottle fixed to the end of a rod, and used for taking the temperatures.
								1·8 -	-	— 0·13 -	-	— 0·08 -	
								1·9 -	-	— 0·35 -	-	— 0·30 -	
								2·0 -	-	— 1·35 -	-	— 1·30 -	
								2·5 -	-	— 1·42 -	-	— 1·37 -	
								2·8 -	-	— 1·48 -	-	— 1·43 -	
								3·0 -	-	— 1·52 -	-	— 1·47 -	
								0 -	-	0·17 -	-	0·22 -	In the open lane on the port bow of the 'Fram'.
								1·0 -	-	0·13 -	-	0·18 -	
								1·1 -	-	0·0 -	-	0·05 -	
								1·2 -	-	— 0·35 -	-	— 0·30 -	
								1·3 -	-	— 0·8 -	-	— 0·75 -	
								1·4 -	-	— 1·35 -	-	— 1·30 -	
								1·5 -	-	— 1·47 -	-	— 1·42 -	
								1·6 -	-	— 1·47 -	-	— 1·42 -	
								1·7 -	-	— 1·50 -	-	— 1·45 -	
								1·7 -	-	— 1·50 -	-	— 1·45 -	
								1·8 -	-	— 1·42 -	-	— 1·37 -	
								1·9 -	-	— 1·45 -	-	— 1·40 -	
								1·9 -	-	— 1·45 -	-	— 1·40 -	
								2·0 -	-	— 1·52 -	-	— 1·47 -	
								2·5 -	-	— 1·48 -	-	— 1·43 -	
								2·8 -	-	— 1·48 -	-	— 1·43 -	
								3·0 -	-	— 1·48 -	-	— 1·43 -	
Aug. 3		81° 5′	127° 19′	WSW	3·0	2·5 -	Cir.str. 10	0 -	-	0·38 -	-	0·43 -	In the open lane on the port bow.
								1 -	-	0·38 -	-	0·43 -	

								1·2 -	-	0·27 -	-	0·32 -	
								1·3 -	-	0·02 -	-	0·07 -	
								1·4 -	-	— 0·35 -	-	— 0·30 -	
								1·5 -	-	— 1·18 -	-	— 1·13 -	
								2·0 -	-	— 1·37 -	-	— 1·32 -	
								2·5 -	-	— 1·42 -	-	— 1·37 -	
								3·0 -	-	— 1·50 -	-	— 1·45 -	
								0 -	-	0·38 -	-	0·43 -	In the water-hole at the kennels near the 'Fram'.
								1 -	-	0·4 -	-	0·45 -	
								1 -	-	0·4 -	-	0·45 -	
								1·5 -	-	0·28 -	-	0·33 -	
								1·7 -	-	0·08 -	-	0·13 -	At a depth of about 1·6 m. there was a layer of soft and porous ice, about 2 cm. thick.
								1·8 -	-	0·0 -	-	0·05 -	
								2·0 -	-	— 0·6 -	-	— 0·55 -	
								2·5 -	-	— 1·33 -	-	— 1·28 -	
								3·0 -	-	— 1·50 -	-	— 1·45 -	
Aug.	6		81° 8′	127° 30′	W b S	1·5	2·6 -	0	0				In the lane on the port bow. The water covered by an ice-crust, about 0·5 cm. thick.
								0·01 -	-	0·0 -	-	0·05 -	In the shade, the thermometer-bulb just below the surface.
								0·1 -	-	0·8 -	-	0·85 -	In the shade.
								0·01 -	-	1·0 -	-	1·05 -	In the sun.
								0·1 -	-	1·0 -	-	1·05 -	
								1·0 -	-	1·0 -	-	1·05 -	
								1·4 -	-	0·2 -	-	0·25 -	
								1·45 -	-	0·08 -	-	0·13 -	
								1·5 -	-	— 0·58 -	-	— 0·53 -	
								2·0 -	-	— 1·25 -	-	— 1·20 -	
								2·5 -	-	— 1·25 -	-	— 1·20 -	
								3·0 -	-	— 1·38 -	-	— 1·33 -	

[1] During the night, the temperature had been below — 1° C.

Date. 1894.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Aug. 11		81° 4·6′	127° 45′	SW	5·4	0·5° C.	Cir.str. 10 Light mist						In the lane on the port bow. The water covered with an ice-crust, about 2 mm. thick, at a distance of 2 m. from the floe; somewhat thicker near the margin of the ice.
								0 m.	Sbg. 114	0·8 °C.	+ 0·05	0·85°C.	The thermometer was moved about in the surface-water.
								0 -	-	0·9 -	-	0·95 -	
								0 -	-	0·95 -	-	1·00 -	
								0 -	-	1·0 -	-	1·05 -	Two samples taken from the surface with the glass bottle.
								0 -	-	1·0 -	-	1·05 -	
								1 -	-	0·3 -	-	0·35 -	
								1·6 -	-	0·03 -	-	0·08 -	No layer of ice was found in the water below the surface. [1]
								1·65 -	-	−0·08 -	-	−0·03 -	
								1·7 -	-	−0·40 -	-	−0·35 -	
								1·85 -	-	−1·46 -	-	−1·41 -	
								2·0 -	-	−1·45 -	-	−1·40 -	
								3·0 -	-	−1·50 -	-	−1·45 -	
Aug. 13	6 p. m.	81° 4·3′	127° 55′	NE b E	1·4	0·7 -	Str. & Fog 10	0 -	-	0·75 -	-	0·80 -	In the lane on port side.
								1 -	-	0·6 -	-	0·65 -	No layer of ice at any depth.
								1·6 -	-	0·02 -	-	0·07 -	
								1·65 -	-	−0·43 -	-	−0·38 -	
								2 -	-	−1·30 -	-	−1·25 -	
								2·5 -	-	−1·40 -	-	−1·35 -	
								3 -	-	−1·50 -	-	−1·45 -	
Aug. 20	0.30 p. m.	81° 5′	128° 7′	0	0	1·0 -	Str. 10	0 -	-	0·62 -	-	0·67 -	In the lane on port side. Remains of a thin ice-crust on the surface of the water. [2]
							Fog	0 -	-	0·62 -	-	0·67 -	
								1 -	-	0·47 -	-	0·52 -	
								1·6 -	-	0·05 -	-	0·10 -	No layer of ice lower down in the water.

								1·65 -	-	0·05 -	-	0·10 -	
								1·7 -	-	— 0·22 -	-	— 0·17 -	
								2 -	-	— 1·30 -	-	— 1·25 -	
								2·5 -	-	— 1·38 -	-	— 1·33 -	
								3 -	-	— 1·45 -	-	— 1·40 -	
Aug. 24	1 p.m.	81° 2′	128°	NW b N 2·7	— 4.0 -	Str. 10		0 -	-	0·08 -	-	0·13 -	In the lane on port side.
								1 -	-	0·15 -	-	0·20 -	
								1 -	-	0·15 -	-	0·20 -	The surface of the water covered with an ice-crust, about 2 cm. thick.
								1·3 -	-	0·05 -	-	0·10 -	
								1·4 -	-	0·00 -	-	0·05 -	
								1·5 -	-	— 0·20 -	-	— 0·15 -	
								2 -	-	— 1·40 -	-	— 1·35 -	
								3 -	-	— 1·45 -	-	— 1·40 -	
Aug. 27	1 p.m.	80° 57′	127° 30′	NW 8·9	— 2·7 -	Str. 10 Heavy snow		0 -	-	— 0·04 -	-	0.01 -	In the lane on the port bow.
								0 -	-	— 0·05 -	-	0·00 -	
								0·5 -	-	— 0·09 -	-	— 0·04 -	
								1 -	-	— 0·17 -	-	— 0·12 -	
								1·25 -	-	— 0·35 -	-	— 0·30 -	
								1·35 -	-	— 1·05 -	-	— 1·00 -	
								1·5 -	-	— 1·50 -	-	— 1·45 -	
								2 -	-	— 1·50 -	-	— 1·45 -	
								3 -	-	— 1·55 -	-	— 1·50 -	
Sept. 1	3 p.m.	81° 10′	125°	NE b E 5·7	— 1·4 -	Str. 10		0 -	-	0·00 -	+ 0·04	0·04 -	In the lane on the port bow.
								0·5 -	-	— 0·13 -	-	— 0·09 -	
								0·8 -	-	— 0·15 -	-	— 0·11 -	
								0·9 -	-	— 0·25 -	-	— 0·21 -	
								1 -	-	— 1·37 -	-	— 1·33 -	
								2 -	-	— 1·57 -	-	— 1·53 -	
								3 -	-	— 1·60 -	-	— 1·56 -	

[1] This ice had probably been formed at about 1·7 m. depth, and had risen to the surface. During the previous night, however, the temperature of the air had been as low as about — 1·6 ° C. F. N.

[2] As the temperature of the air was above freezing-point, and had also been so during the night, it is evident that the ice-crust on the surface must have been formed by ice-needles, which have floated up from a depth of about 1·6 m., where they had been formed as usual at the boundary between the surface-layer of nearly fresh water, produced by the melting of snow and ice, and the underlying cold sea-water. The ice formed at this depth must rise to the surface here in the broad lane, as the margins of the floes are too far apart to act as an attachment for the formation of a layer of ice below the surface. F. N.

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Sept. 7	1 p. m.	81° 8′	122° 50′	NW	5·3	— 6·0° C.	Str. 10	0 m.	Sbg. 114	— 0·13° C.	+ 0·04	— 0·09° C.	In the water-hole.
								1 -	-	— 0·20 -	-	— 0·16 -	Under the layer of ice, covering the surface of the water, there was a layer, about 20 cm. thick, of ice-needles, which were very delicate in the lowest stratum.[1] At a depth of 1·2 m., there was a layer of solid ice, about 3 cm. thick, porous on the lower surface.
								1 -	-	— 0·20 -	-	— 0·16 -	
								1·25 -	-	— 1·40 -	-	— 1·36 -	
								1·5 -	-	— 1·60 -	-	— 1·56 -	
								2 -	-	— 1·60 -	-	— 1·56 -	
								3 -	-	— 1·60 -	-	— 1·56 -	
Sept. 10	3 p. m.	81° 5′	121° 50′	SSE	3·8	— 4·5 -	Cir.cum. 10	0 -	-	— 0·13 -	-	— 0·09 -	In the water-hole.
								1 -	-	— 0·20 -	-	— 0·16 -	At a depth of 0·75 m., there was a layer of ice similar to that found on Sept. 7th, at 1·2 m. depth.
								1·5 -	-	— 1·35 -	-	— 1·31 -	
								2 -	-	— 1·58 -	-	— 1·54 -	
								2·5 -	-	— 1·60 -	-	— 1·56 -	
								3 -	-	— 1·60 -	-	— 1·56 -	
Sept. 14	1 p. m.	81° 10′	122°	SbW	4·8	— 2·5 -	Str. 10	0 -	-	— 0·14 -	-	— 0·10 -	
								0·5 -	-	— 0·20 -	-	— 0·16 -	
								1 -	-	— 0·20 -	-	— 0·16 -	Layer of ice, about 12 cm. thick, at a depth of 1·15 m.
								1·5 -	-	— 1·57 -	-	— 1·53 -	
								2 -	-	— 1·57 -	-	— 1·53 -	
								3 -	-	— 1·60 -	-	— 1·56 -	
Sept. 17	1 p. m.	81° 22′	124° 6′	WSW	3·4	— 7·6 -	Str. 10	0 -	-	— 0·13 -	-	— 0·09 -	
								0·5 -	-	— 0·20 -	-	— 0·16 -	
								1 -	-	— 0·20 -	-	— 0·16 -	Layer of ice, about 8 cm. thick, at 1 m. depth.
								1·5 -	-	— 1·60 -	-	— 1·56 -	
								2 -	-	— 1·60 -	-	— 1·56 -	
								2·5 -	-	— 1·60 -	-	— 1·56 -	
								3 -	-	— 1·60 -	-	— 1·56 -	

Sept. 21	4 p.m.	81° 12′	123° 35′	SE b E	4·0	— 14·2 -	Cir.str.	10	0 -	-	— 0·13 -	-	— 0·09 -	
									1 -	-	— 0·20 -	-	— 0·16 -	Layer of ice, similar to Sept. 17th.
									1·5 -	-	— 1·53 -	-	— 1·49 -	
									3 -	-	— 1·60 -	-	— 1·56 -	
Sept. 24	1 p.m.	81° 20′	122° 31′	NW b N	3·8	— 14·2 -	Cum.str.	10	0 -	-	— 0·15 -	-	— 0·11 -	
									0·5 -	-	— 0·15 -	-	— 0·11 -	
									1·0 -	-	— 0·20 -	-	— 0·16 -	Layer of ice, about 15 cm. thick, at 1 m. depth.
									1·5 -	-	— 1·60 -	-	— 1·56 -	
									2 -	-	— 1·60 -	-	— 1·56 -	
									3 -	-	— 1·60 -	-	— 1·56 -	
Oct. 1	1 p.m.	81° 5′	122° 1′	NW	3·8	— 14·9 -	Cir.str.	10	0 -	-	— 0·15 -	-	— 0·11 -	
									1 -	-	— 0·20 -	-	— 0·16 -	
									1·5 -	-	— 1·60 -	-	— 1·56 -	Layer of ice as before.
									2 -	-	— 1·60 -	-	— 1·56 -	
									3 -	-	— 1·60 -	-	— 1·56 -	
Oct. 22	Noon.	82° 1′	114° 40′	S	2·4	— 33·9 -	0	0	0 -	-	— 0·20 -	-	— 0·16 -	
Oct. 29	11 a.m.	82° 11′	113° 13′	ESE	5·1	— 26·4 -	Hazy	10	0 -	-	— 0·25 -	-	— 0·21 -	
Nov. 3	1 p.m.	82° 6′	111° 30′	E	4·5	— 34 -	0	0	0 -	-	— 0·25 -	+ 0·03	— 0·22 -	
									0 -	-	— 0·30 -	-	— 0·27 -	Taken with glass bottle.
									1 -	-	— 0·38 -	-	— 0·35 -	
									2 -	-	— 1·68 -	-	— 1·65 -	
									3 -	-	— 1·70 -	-	— 1·67 -	
Nov. 12	2 p.m.	82° 9′	110° 18′	NNE	5·8	— 35·4 -	0	0	0 -	-	— 0·38 -	+0·03?	— 0·35 -	
									3 -	-	— 1·83 -	-	— 1·80 -	Read in the glass bottle while it was standing on the ice.
									3 -	-	— 1·75 -	-	— 1·72 -	Read in the glass-bottle while it was left hanging in the water.

[1] This layer was evidently composed of ice-needles floating up from below, where they had been formed at the boundary between the upper fresh-water layer and the underlying salt-water at a depth of about 1·2 m. F. N.

Date. 1894.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Nov. 19	p. m.	82° 4′	111°	W b S	5·6	— 15·6° C.	Str. 10	0 m.	Sbg. 114?	— 0·52° C.[1]	+0.03?	— 0·49° C.	[1] Taken with glass bottle. The bottle was left hanging in the water during the reading.
								0 -	-	— 0·50 -	-	— 0·47 -	
								1 -	-	— 0·55 -	-	— 0·52 -	
								1·5 -	-	— 0·80 -	-	— 0·77 -	
								1·75 -	-	— 1·65 -	-	— 1·62 -	
								2 -	-	— 1·70 -	-	— 1·67 -	
								3 -	-	— 1·70 -	-	— 1·67 -	
Nov. 30	a. m.	82° 10′	110° 40′	ESE	0·0	— 35·4 -	0 0	0 -	-	— 0·70 -	-	— 0·67 -	
								1 -	-	— 0·80 -	-	— 0·77 -	
								1·5 -	-	— 1·50 -	-	— 1·47 -	
								2 -	-	— 1·70 -	-	— 1·67 -	
								3 -	-	— 1·70 -	-	— 1·67 -	
Dec. 4	p. m.	82° 13′	109° 57′	ESE	4·4	— 34·2 -	0 0	0 -	-	— 0·85 -	-	— 0·82 -	
								0 -	-	— 0·89 -[1]	-	— 0·86 -	[1] Taken with glass bottle, where the indication cannot be read so accurately.
								1 -	-	— 0·95 -	-	— 0·92 -	
								1·5 -	-	— 1·55 -	-	— 1·52 -	
								2 -	-	— 1·75 -	-	— 1·72 -	
								3 -	-	— 1·75 -	-	— 1·72 -	
Dec. 11	p. m.	82° 28′	108° 28′	SSE	9·0	— 33·6 -	Str. 10 Heavy snow	0 -	-	— 1·40 -	-	— 1·37 -	Taken with glass bottle.
								1 -	-	— 1·45 -	-	— 1·42 -	
								1·5 -	-	— 1·80 -	-	— 1·77 -	
								2 -	-	— 1·80 -	-	— 1·77 -	
								3 -	-	— 1·80 -	-	— 1·77 -	
Dec. 18	p. m.	82° 50·5′	105°	E	3·7	— 42·2 -	0 0	0 -	-	— 1·80 -	-	— 1·77 -	
								1·5 -	-	— 1·85 -	-	— 1·82 -	
								3 -	-	— 1·85 -	-	— 1·82 -	
Dec. 28	p. m.	83° 20′	102°	W	5·3	— 32·6 -	Cir.str. 10	0 -	-	— 1·80 -	-	— 1·77 -	
								0 -	-	— 1·85 -[1]	-	— 1·82 -	[1] Taken with glass bottle; took the bottle out of the water during reading.
								2 -	-	— 1·85 -	-	— 1·82 -	

1895													
Jan. 2	p. m.	83° 24′	102° 38′	WSW 3·6	— 31·2 -	Cir.str. 10	0 -	Sbg. 114?	— 1·82 -	+0·03?	— 1·79 -		
							0 -	-	— 1·85 -	-	— 1·82 -	Taken with glass bottle.	
							2 -	-	— 1·85 -	-	— 1·82 -	—	— —
							4 -	-	— 1·90 -	-	— 1·87 -	—	— —
March 13	10 a. m.	84° 3′	101° 52′	SSE 3·2	— 25·5 -	0 0	0 -	Sbg. 114	— 1·80 -	+0·02?	— 1·78 -		
April 27	Noon.	84° 12′	93° 45′	NW 3·9	— 28·9 -	0 0	0 -	-	— 1·80 -	-	— 1·78 -		
May 13	Noon.	84° 39′	88° 44′	E b N 3·6	— 10·4 -	Str. 10 Snow	0 -	-	— 1·72 -	-	— 1·70 -		
May 20	2 p. m.	84° 33′	85° 08′	E b S 0·0	— 10·2 -	Cir.str. 10	0 -	-	— 1·75 -	-	— 1·73 -		
							1 -	-	— 1·80 -	-	— 1·78 -		
							2 -	-	— 1·75 -	-	— 1·73 -		
							3 -	-	— 1·75 -	-	— 1·73 -		
							4 -	-	— 1·75 -	-	— 1·73 -		
May 30	a. m.	84° 34′	82° 46′	SW b W 4·8	— 4·5 -	Ci.cu.st. 10	0 -	-	— 1·75 -	-	— 1·73 -		
							1 -	-	— 1·77 -	-	— 1·75 -		
							2 -	-	— 1·77 -	-	— 1·75 -		
							3 -	-	— 1·77 -	-	— 1·75 -		
							4 -	-	— 1·77 -	-	— 1.75 -		
June 7	p. m.	84° 33′	84° 30′	NW b W 4·0	— 4·9 -	Cir.cum 1	0 -	-	— 1·72 -	-	— 1·70 -		
							1 -	-	— 1·72 -	-	— 1·70 -		
							2 -	-	— 1·72 -	-	— 1·70 -		
							3 -	-	— 1·72 -	-	— 1·70 -		
							4 -	-	— 1·72 -	-	— 1·70 -		
June 14	p. m.	84° 52′	81° 0′	E 6·1	— 0·4 -	Str. 10	0 -	Sbg. 114?	— 1·65 -	-	— 1·63 -		
							0 -	-	— 1·70 -	-	— 1·68 -		
							2 -	-	— 1·72 -	-	— 1·70 -		
							4 -	-	— 1·72 -	-	— 1·70 -		
							0 -	-	— 1·60 -	-	— 1·58 -	In the water-hole.	
							2 -	-	— 1·65 -	-	— 1·63 -		
							4 -	-	— 1·75 -	-	— 1·73 -		
July 6	a. m.	84° 45′	75° 20′	E 7·6	— 0·1 -	Str. 10 Hail	0 -	Sbg. 118	— 0·25 -	+ 0·03	— 0·22 -		
							0 -	-	— 0·36 -	-	— 0·33 -	In the glass bottle.	

Date. 1895.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
July 6	a. m.	84° 45′	75° 20′	E	7·6	— 0·1°C.	Str. 10 Hail	1 m.	Sbg. 118	— 1·75°C.	+ 0·03	— 1·72°C.	
								2 -	-	— 1·76 -	-	— 1·73 -	
								3 -	-	— 1·78 -	-	— 1·75 -	
								4 -	-	— 1·60 -	-	— 1·57 -	
July 13	p. m.	84° 41′	76° 1′	SE b S	2·8	1·4 -	0 0	0 -	-	2·00 -	-	2·03 -	Taken with glass bottle.
								0 -	-	2·35 -	-	2·38 -	
								0 -	-	2·60 -	-	2·63 -	
								0·1 -	-	2·60 -	-	2·63 -	
								0·15 -	-	1·30 -	-	1·33 -	
								0·25 -	-	— 0·30 -	-	— 0·27 -	
								0·5 -	-	— 1·72 -	-	— 1·69 -	
								1 -	-	— 1·72 -	-	— 1·69 -	
								2 -	-	— 1·72 -	-	— 1·69 -	
								3 -	-	— 1·70 -	-	— 1·67 -	
								4 -	-	— 1·52 -	-	— 1·49 -	
July 20	p. m.	84° 39′	73° 30′	NNE	3·7	— 0·2 -	Cir.str. 10 Fog	0 -	-	0·46 -	-	0·49 -	In the lane.
								0·5 -	-	0·40 -	-	0·43 -	
								0·75 -	-	— 0·40 -	-	— 0·37 -	
								1 -	-	— 1·48 -	-	— 1·45 -	
								2 -	-	— 1·72 -	-	— 1·69 -	
								3 -	-	— 1·70 -	-	— 1·67 -	
								4 -	-	— 1·68 -	-	— 1·65 -	
July 27	p. m.	84° 29′	73° 30′	SW b W	9·0	— 1·0 -	Cir.cu.st. 9 Snow	0 -	Sbg. 118?	— 0·45 -	+0·03?	— 0·42 -	
								0·5 -	-	— 0·50 -	-	— 0·47 -	
								1 -	-	— 0·90 -	-	— 0·87 -	
								1·25 -	-	— 1·68 -	-	— 1·65 -	
								1·5 -	-	— 1·72 -	-	— 1·69 -	
								3 -	-	— 1·72 -	-	— 1·69 -	
								4 -	-	— 1·70 -	-	— 1·67 -	

Aug. 4	a. m.	84° 36′	77° 48′	ESE 4·6	0·4 -	Cir.cum. 8	0 -	Sbg. 118	— 1·10 -	+ 0.04	— 1·06 -	
							0·5 -	-	— 1·60 -	-	— 1·56 -	
							1 -	-	— 1·65 -	-	— 1·61 -	
							1·5 -	-	— 1·68 -	-	— 1·64 -	
							3 -	-	— 1·68 -	-	— 1·64 -	
							3 -	-	— 1·60 - [1]	-	— 1·56 -	[1] Taken first; the bottle probably not quite cooled.
							4 -	-	— 1·70 -	-	— 1·66 -	
Aug. 10	p. m.	84° 34′	76° 54′	W 4·4	— 1·8 -	0 0	0 -	Sbg. 118?	— 1·63 -	+0·04?	— 1·59 -	
							0·5 -	-	— 1·65 -	-	— 1·61 -	
							1 -	-	— 1·65 -	-	— 1·61 -	
							2 -	-	— 1·65 -	-	— 1·61 -	
							4 -	-	— 1·65 -	-	— 1·61 -	
Aug. 17	p. m.	84° 25′	75° 30′	WNW 5·3	— 4·8 -	Cir.cum. 10	0 -	-	— 1·32 -	-	— 1·28 -	
							0 -	-	— 1·26 -	-	— 1·22 -	
							1 -	-	— 1·60 -	-	— 1·56 -	
							2·5 -	-	— 1·75 -	-	— 1·71 -	
							5 -	-	— 1·73 -	-	— 1·69 -	
Aug. 24	4 p. m.	84° 13′	78° 54′	E 4·0	— 3·3 -	Cum.str. 10	0 -	Sbg. 118	— 1·78 -	+ 0·04	— 1·74 -	
							2 -	-	— 1·78 -	-	— 1·74 -	
							5 -	-	— 1·76 -	-	— 1·72 -	
Sept. 9	4 p. m.	84° 56′	78° 33′	ENE 3·6	— 7·8 -	Cir.str. 10	0 -	-	— 1·74 -	+ 0·03	— 1·71 -	
							2·5 -	-	— 1·75 -	-	— 1·72 -	
							5 -	-	— 1·74 -	-	— 1·71 -	
							6·5 -	-	— 1·74 -	-	— 1·71 -	
Sept. 14	p. m.	85° 5′	78° 45′	SW b S 5.9	— 6·2 -	Str. 10	0 -	-	— 1·78 -	-	— 1·75 -	
							0·25 -	-	— 1·78 -	-	— 1·75 -	
							5 -	-	— 1·78 -	-	— 1·75 -	
Sept. 24	p. m.	85° 7′	79° 7′	NNE 3·2	— 22·6 -	0 0	0 -	-	— 1·78 -	+ 0·02	— 1·76 -	
							5 -	-	— 1·78 -	-	— 1·76 -	
Oct. 5	p. m.	85° 9′	78° 44′	WNW 4·8	— 11·4 -	Str. Fog. 10	1 -	-	— 1·74 -	0·0	— 1·74 -	
							5 -	-	— 1·76 -	-	— 1·76 -	
Nov. 12	p. m.	85° 52′	66° 11′	S b W 2·3	— 27·2 -	0 0	1 -	-	— 1·80 -	-	— 1·80 -	
							5 -	-	— 1·80 -	-	— 1·80 -	

Date. 1895.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.	Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Dec. 9	p. m.	85° 25′	53° 47′	E b S	2·6	— 38·4° C.	0 0	0 m.	Sbg. 118	— 1·85° C.	0.0	— 1·85° C.	
								5 -	-	— 1·85 -	-	— 1·85 -	
Dec. 30	p. m.	85° 23′	47° 5′	ENE	2·3	— 40·0 -	0 0	0 -	-	— 1·85 -	-	— 1·85 -	
								5 -	-	— 1·90 -	-	— 1·90 -	
1896.													
Jan. 19	p. m.	84° 58′	39° 20′	SE b S	6·6	— 21·2 -	Cir.str. 10 Heavy snow	0 -	-	— 1·90 -	-	— 1·90 -	
								5 -	-	— 1·92 -	-	— 1·92 -	
Feb. 14	p. m.	84° 19′	22° 52′	SSE	7·0	— 34·8 -	Str. 10	0 -	-	— 1·92 -	-	— 1·92 -	
								5 -	-	— 1·92 -	-	— 1·92 -	
Apr. 4	a. m.	84° 25′	22° 45′	SW	1·8	— 14·3 -	Cir. Str. Fog Snow 10	0 -	-	— 1·92 -	-	— 1·92 -	2 observations.
								5 -	-	— 1·95 -	-	— 1·95 -	— —
Apr. 22	p. m.	84° 6′	12° 26′	E	5·2	— 15·3 -	0 0	0 -	-	— 1·92 -	-	— 1·92 -	
								5 -	-	— 1·92 -	-	— 1·92 -	
May 4	p. m.	84° 7′	11° 22′	ENE	1·9	— 13·8 -	Cir.cu.st. 10	0 -	-	— 1·92 -	-	— 1·92 -	
								5 -	-	— 1·95 -	-	— 1·95 -	
May 23	p. m.	83° 59′	12° 28′	SW b S	8·5	0·9 -	Str. 10	0 -	-	— 1·90 -	-	— 1·90 -	
								5 -	-	— 1·90 -	-	— 1·90 -	
June 5	p. m.	83° 12′	13° 3′	SW b W	2·4	— 3·5 -	- 10	0 -	-	— 1·90 -	-	— 1·90 -	
								5 -	-	— 1·90 -	-	— 1·90 -	
June 20	p. m.	82° 55′	11° 50′	SW b W	2·4	2·4 -	- 10	0 -	-	— 1.80 -	-	— 1·80 -	
								0 -	-	— 1·80 -	-	— 1·80 -	
								0 -	-	— 1·78 -	-	— 1·78 -	
								5 -	-	— 1·82 -	-	— 1·82 -	
								5 -	-	— 1·82 -	-	— 1·82 -	
								10 -	-	— 1·80 -	-	— 1·80 -	
								10 -	-	— 1·80 -	-	— 1·80 -	

June 30[1]	p. m.	82° 57′	12° 5′	E[1]	7·2[1]	— 0·4 -	Str.	10	0 -	Sbg. 118	— 1·75 -	-	— 1·75 -	
									1 -	-	— 1·8 -	-	— 1·8 -	
									5 -	-	— 1·8 -	-	— 1·8 -	
									10 -	-	— 1·8 -	-	— 1·8 -	
July 14	a. m.	83° 13′	14° 10′	SSW	5·6	1·4 -	Str. Fog. Fine rain.	10	0 -	-	0·08 -	-	0·08 -	
									0·25 -	-	— 0·02 -	-	— 0·02 -	
									0·50 -	-	— 0·42 -	-	— 0·42 -	
									0·75 -	-	— 1·2 -	-	— 1·2 -	
									1 -	-	— 1·72 -	-	— 1·72 -	
									2 -	-	— 1·8 -	-	— 1·8 -	
									5 -	-	— 1·8 -	-	— 1·8 -	
									10 -	-	— 1·8 -	-	— 1·8 -	
July 21	4 a. m.			WNW	0·0	— 1·8 -	0	0	0 -	Casella 72327	— 1·5 -	— 0·1	— 1·6 -	
	8 a. m.		12° 52′	SW b S	2·4	— 0·8 -	0	0	0 -	-	— 1·3 -	-	— 1·4 -	
	Noon.	82° 41′		SSE	1·9	0·4 -	0	0	0 -	-	— 1·1 -	-	— 1·2 -	
	4 p. m.			SE	2·0	0·2 -	Cir.	2	0 -	-	— 1·5 -	-	— 1·6 -	
	9 p. m.			NNE	1·5	0·2 -	-	1	0 -	-	— 1·3 -	-	— 1·4 -	
	Midn.	82° 33′	12° 49′	ENE	1·8	— 0·1 -	-	2	0 -	-	— 1·2 -	-	— 1·3 -	
July 22	4 a. m.			NNE	3·2	— 0·5 -	Str.	10	0 -	-	— 1·1 -	-	— 1·2 -	
	8 a. m.			N b E	5·3	0·1 -	-	10	0 -	Sbg. 105?[2]	— 1·5 -	+0·4?[2]	— 1·1 -	
	0.15 p. m.	82° 18′	13° 18′	N	5·9	0·6 -	-	10	0 -	-	— 1·2 -	-	— 0·8 -	
	8 p. m.			NNW	8·1	0·9 -	-	10	0 -	-	— 1·4 -	-	— 1·0 -	
	Midn.			NNW	8·7	0·8 -	-	10	0 -	-	— 1·45 -	-	— 1·05 -	

[1] In the explanation of the *fifth column* on p. 65, it is stated that for the last part of the voyage, "after April 30th, 1896, the direction of the wind and its velocity are simply taken out of the journal, as there has not yet been time to correct them," etc. When the present sheet was going to press, the direction and the velocity of the wind were, however, corrected to their true values, which are therefore introduced for the period from June 30th to Aug. 19th, 1896. The above statement will thus be correct only for the last four days on p. 96, May 4th to June 20th, 1896.

[2] After July 21st, 1896, the number of the thermometer used for the surface-temperature is only stated on July 29th, 1896, 4 p. m., when Sbg. 105 was used. Capt. Scott-Hansen is, however, strongly inclined to believe that this thermometer, which was used for the air temperature, was also used for taking the temperature of the sea-surface on the other dates after July 21st. The stem of Sbg. 105 was broken at the top and was repaired on July 14th, 1896. When the thermometer came to Christiania, its correction was determined by Prof. Mohn to be + 0·4° C. at zero.

Date. 1896.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.		Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
July 23	4 a. m.			NNW	9·0	0·5 °C.	Str.	10	0 m.	Sbg. 105?	— 1·5 °C.	+ 0·4?	— 1·1 °C.	
	8 a. m.			NNW	8·4	0·7 -	-	10	0 -	-	— 1·4 -	-	— 1·0 -	
	1.15 p. m.	82° 8′	12° 57′	N	7·8	0·4 -	- Sleet	10	0 -	-	— 1·5 -	-	— 1·1 -	
	4 p. m.			NNW	6·4	0·2 -	-	10	0 -	-	— 1·4 -	-	— 1·0 -	
	8 p. m.			NNW	7·2	0·2 -	-	10	0 -	-	— 1·5 -	-	— 1·1 -	
	Midn.			NNW	6·2	— 0·5 -	Str.	10	0 -	-	— 1·7 -	-	— 1·3 -	
July 24	4 a. m.	82° 3′	12° 36′	NW	5·4	— 1·1 -	Cir.str.	10	0 -		— 1·6 -	-	— 1·2 -	
	8 a. m.			NW b W	4·8	— 1·0 -	0	0	0 -	-	— 1·5 -	-	— 1·1 -	
	Noon.	82° 2′		W b N	2·8	— 1·1 -	0	0	0 -	-	— 1·3 -	-	— 0·9 -	
	4 p. m.		12° 40′	W	3·6	— 0·2 -	Cir.	2	0 -	-	— 1·0 -	-	— 0·6 -	
	8.15 p. m.	82° 2′		SW b W	2·8	— 1·4 -	Cir.cum.	10	0 -	-	— 1·5 -	-	— 1·1 -	
	Midn.			S	2·8	0·0 -	Str.	10	0 -	-	— 1·45 -	-	— 1·05 -	
July 25	4 a. m.			SSE	2·0		Cir.cum.	10	0 -	-	— 1·0 -	-	— 0·6 -	
	8.15 a. m.			SSE	1·7	1·4 -	Cu.st.	10	0 -	-	— 1·5 -	-	— 1·1 -	
	6 p. m.			SE	0·7	— 0·3 -	Cum.	2	0 -	-	— 1·0 -	-	— 0·6 -	
	8.15 p. m.		12° 35′	E b N	2·4	— 0·2 -	Cir.cum.	4	0 -	-	— 1·45 -	-	— 1·05 -	
	Midn.	81° 52′		ENE	1·6	— 0·2 -	-	1	0 -	-	— 1·5 -	-	— 1·1 -	
July 26	4 a. m.			E b N	2·5	— 0·7 -	0	0	0 -	-	— 1·5 -	-	— 1·1 -	
	8 a. m.			ENE	1·3	0·0 -	0	0	0 -	-	— 1·4 -	-	— 1·0 -	
	Noon.	81° 49′		N b E	4·5	— 1·1 -	Cir. Fog	10	0 -	-	— 1·5 -	-	— 1·1 -	
	4 p. m.			N b E	5·6	— 0·2 -	Cir.str. Fog	10	0 -	-	— 1·5 -	-	— 1·1 -	
	8.15 p. m.			N b W	4·6	— 0·2 -	Cir.str.	10	0 -	-	— 1·5 -	-	— 1·1 -	
	Midn.			NNE	5·6	0·0 -	-	10	0 -	-	— 1·5 -	-	— 1·1 -	
July 27	4 a. m.		12° 54′	NNE	5·1	0·6 -	Cir.cum.	5	0 -	-	— 1·5 -	-	— 1·1 -	
	7 a. m.			N b W	3·7	0·1 -	0	0	0 -	-	— 1·55 -	-	— 1·15 -	
	Noon.	81° 45′	12° 45′	NNW	4·2	1·4 -	0	0	0 -	-	— 1·3 -	-	— 0·9 -	
	Midn.	81° 32′		NNW	4·4	— 0·2 -	0	0	0 -	-	— 1·5 -	-	— 1·1 -	
July 28	4 a. m.		12° 32′	NW b N	3·3	— 0·8 -	0	0	0 -	-	— 1·6 -	-	— 1·2 -	
	8 a. m.			Calm		1·5 -	0	0	0 -	-	— 1·3 -	-	— 0·9 -	

	0.30 p.m.	81° 35′		SW b W	2·2	0·4 -	0	0	0 -	-	— 1·2 -	-	— 0·8 -	
	5 p.m.			SW	2·4	2·4 -	0	0	0 -	-	— 1·2 -	-	— 0·8 -	
	8 p.m.			S b W	2·0	0·2 -	Cir.cum.	10	0 -	-	— 1·2 -	-	— 0·8 -	
	Midn.	81° 30′		S b E	1·8	0·1 -	-	10	0 -	-	— 1·45 -	-	— 1·05 -	
July 29	4 a.m.			SW b W	5·5	— 0·4 -	Cir.str.	10	0 -	-	— 1·5 -	-	— 1·1 -	
	8 a.m.			SW b W	4·1	0·6 -	Cir.str. Fog	10	0 -	-	— 1·45 -	-	— 1·05 -	
	Noon.	81° 30′	12° 40′	S b E	1·3	1·8 -	Cir.str.	3	0 -	-	— 1·20 -	-	— 0·8 -	
	4 p.m.			S	2·0	1·0 -	Str. Fog Fine rain	10	0 -	-[1]	— 1·65 -	-	— 1·25 -	[1] It is expressly stated in the journal that this series of temperatures was taken with Sbg. 105.
									1 -	-	— 1·7 -	-	— 1·3 -	
									2 -	-	— 1·75 -	-	— 1·35 -	
									3 -	-	— 1·8 -	-	— 1·4 -	
									5 -	-	— 1·8 -	-	— 1·4 -	
									10 -	-	— 1·8 -	-	— 1·4 -	
	8 p.m.			W	2·2	— 0·2 -	Str.	10	0 -	-	— 1·4 -	-	— 1·0 -	
	Midn.			Calm		— 0·3 -	Str. Fog	10	0 -	-	— 1·2 -	-	— 0·8 -	
July 30	4 a.m.			SE	2·5	0·2 -	-	10	0 -	-	— 1·1 -	-	— 0·7 -	
	8 a.m.			ENE	1·0	0·6 -	-	10	0 -	-	— 1·2 -	-	— 0·8 -	
	Noon.	81° 35′	13° 0′	ESE	2·3	0·4 -	Cir.str. Fog	10	0 -	-	— 0·9 -	-	— 0·5 -	
	4 p.m.			Calm		1·0 -	Str. Fog	10	0 -	-	— 1·2 -	-	— 0·8 -	
	8.15 p.m.			ENE	2·2	— 0·3 -	-	10	0 -	-	— 0·9 -	-	— 0·5 -	
	Midn.			NNE	3·1	— 1·8 -	-	10	0 -	-	— 1·0 -	-	— 0·6 -	
July 31	4 a.m.			NNE	3·6	— 1·7 -	-	10	0 -	-	— 1·0 -	-	— 0·6 -	
	8 a.m.			NNE	3·3	— 0·7 -	-	10	0 -	-	— 1·4 -	-	— 1·0 -	
	Noon.	81° 27′		NNE	3·8	0·4 -	-	10	0 -	-	— 1·4 -	-	— 1·0 -	
	4 p.m.			NE	2·6	0·6 -	Str.	10	0 -	-	0·0 -	-	0·4 -	2 observations.
	8 p.m.			NE	2·8	0·2 -	-	10	0 -	-	— 0·1 -	-	0·3 -	
	Midn.			NE	1·4	0·0 -	-	10	0 -	-	— 0·2 -	-	0·2 -	
Aug. 1	4 a.m.			N b W	3·0	— 0·2 -	-	10	0 -	-	— 0·35 -	-	0·05 -	
	8 a.m.		13° 30′	NW b N	3·0	0·4 -	Str.cum.	10	0 -	-	— 1·2 -	-	— 0·8 -	
	0.20 p.m.	81° 30′		NW b W	4·4	0·1 -	Str. snow	10	0 -	-	— 1·35 -	-	— 0·95 -	
	4 p.m.			WNW	3·6	0·0 -	Str. sleet	10	0 -	-	— 0·5 -	-	— 0·1 -	
	8.15 p.m.			NW	3·5	0·0 -	-	10	0 -	-	— 1·35 -	-	— 0·95 -	
	Midn.			W	3·0	— 0·1 -	-	10	0 -	-	— 1·0 -	-	— 0·6 -	

Date. 1896.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds		Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Aug. 2	4 a.m.			W	3·5	—0·4° C.	Str. sleet	10	0 m.	Sbg. 105?	—0·6 °C.	+0·4?	—0·2 °C.	
	8 a.m.		13° 48′	SSW	3·9	—0·2 -	Str. Fog	10	0 -	-	—0·6 -	-	—0·2 -	
	Noon.	81° 26′		SW b S	3·9	0·6 -	-	10	0 -	-	—0·5 -	-	—0·1 -	
	4 p.m.			S	3·3	—0·2 -	Str. sleet	10	0 -	-	—0·2 -	-	0·2 -	
	8 p.m.			SSE	2·5	—0·4 -	-	10	0 -	-	—0·45 -	-	—0·05 -	
	Midn.			SE b E	2·0	0·2 -	-	10	0 -	-	—0·5 -	-	—0·1 -	
Aug. 3	4 a.m.			E b N	4·8	0·5 -	-	10	0 -	-	—0·25 -	-	0·15 -	
	8 a.m.			E b N	6·0	0·5 -	-	10	0 -	-	—0·5 -	-	—0·1 -	
	Noon.	81° 22′		E b N	6·3	0·6 -	-	10	0 -	-	—1·3 -	-	—0·9 -	
	4 p.m.			ENE	8·3	0·2 -	Str. sleet		0 -	-	—1·0 -	-	—0·6 -	
	8 p.m.			NE b E	8·7	—0·4 -	-	10	0 -	-	—1·5 -	-	—1·1 -	
	Midn.			NE	7·7	—0·9 -	-	10	0 -	-	—1·6 -	-	—1·2 -	
Aug. 4	4 a.m.	81° 20′	12° 23′	NE b N	8·3	—1·1 -	Str.	8	0 -	-	—1·4 -	-	—1·0 -	
	8 a.m.			N	6·8	—1·8 -	-	10	0 -	-	—1·55 -	-	—1·15 -	
	Noon.			N	8·6	0·0 -	-	10	0 -	-	—1·5 -	-	—1·1 -	
Aug. 5	8 a.m.	81° 16′	12° 28′	NW	9·0	—0·4 -	Str. sleet	10	0 -	-	—1·5 -	-	—1·1 -	
	4 p.m.			NW b W	7·6	—0·6 -	Str. snow	10	0 -	-	—1·5 -	-	—1·1 -	
	8 p.m.			NW b W	6·9	—0·3 -	Str.	10	0 -	-	—1·5 -	-	—1·1 -	
	Midn.			NW	6·5	—0·8 -	- Heavy snow	10	0 -	-	—1·6 -	-	—1·2 -	
Aug. 6	4 a.m.			NW	7·3	—0·3 -	Str.	10	0 -	-	—1·5 -	-	—1·1 -	
	8 a.m.			NW b N	6·5	0·0 -	-	10	0 -	-	—1·55 -	-	—1·15 -	
	Noon.	81° 12′	12° 32′	NW	6·6	0·0 -	-	10	0 -	-	—1·5 -	-	—1·1 -	
	8 p.m.			NW	4·4	0·2 -	-	10	0 -	-	—1·5 -	-	—1·1 -	
	Midn.			NW b W	4·6	0·0 -	-	10	0 -	-	—1·6 -	-	—1·2 -	
Aug. 7	4 a.m.			NW b W	3·1	—0·2 -	-	10	0 -	-	—1·5 -	-	—1·1 -	
	8 a.m.			NW b W	3·2	0·2 -	- Fine snow	10	0 -	-	—1·45 -	-	—1·05 -	

	Noon.	81° 8′	12° 36′	W	4·9	0·4 -	Str.	10	0 -	-	— 1·25 -	-	— 0·85 -
	4 p. m.			WNW	3·2	0·2 -	-	10	0 -	-	— 1·35 -	-	— 0·95 -
	8 p. m.			W	2·7	— 0·1 -	- Fog	10	0 -	-	— 1·5 -	-	— 1·1 -
	Midn.			WSW	3·2	— 0·1 -	Str.	10	0 -	-	— 1·0 -	-	— 0·6 -
Aug. 8	4 a. m.		12° 40′	WSW	4·4	— 0·8 -	-	10	0 -	-	— 1·0 -	-	— 0·6 -
	8 a. m.			W	4·1	— 1·2 -	-	10	0 -	-	— 1·0 -	-	— 0·6 -
	Noon.	81° 5′		W	4·0	— 0·4 -	-	10	0 -	-	— 1·3 -	-	— 0·9 -
	5 p. m.			WSW	2·3	— 0·1 -	Cir.str.	10	0 -	-	— 1·6 -	-	— 1·2 -
	8 p. m.			SW	3·2	0·2 -	Str.	10	0 -	-	— 1·3 -	-	— 0·9 -
	Midn.			SSW	2·8	0·2 -	Cir.str.	10	0 -	-	— 1·5 -	-	— 1·1 -
Aug. 9	4 a. m.			SSW	1·8	1·2 -	Str.	10	0 -	-	— 1·5 -	-	— 1·1 -
	8 a. m.			Calm		1·0 -	-	10	0 -	-	— 1·5 -	-	— 1·1 -
	Noon.	81° 5′	12° 40′	ESE	1·3	1·3 -	Cir.cu.st.	10	0 -	-	— 1·3 -	-	— 0·9 -
	4 p. m.			E b S	2·8	0·8 -	Cir.str. cum.	8	0 -	-	— 1·3 -	-	— 0·9 -
	8.15 p. m.			E	1·8	0·4 -	Cir.str.	10	0 -	-	— 1·5 -	-	— 1·1 -
	Midn.			SSE	2·0	1·2 -	Str.	10	0 -	-	— 1·45 -	-	— 1·05 -
Aug. 10	4 a. m.			SSE	2·0	0·6 -	Str.cum. sleet	10	0 -	-	— 1·6 -	-	— 1·2 -
	9 a. m.			SSE	2·8	1·2 -	Str.	10	0 -	-	— 1·0 -	-	— 0·6 -
	Noon.	81° 0′	12° 25′	S	2·2	1·6 -	-	10	0 -	-	— 1·5 -	-	— 1·1 -
	4 p. m.			S b E	2·4	0·8 -	Cir.str.	10	0 -	-	— 0·9 -	-	— 0·5 -
	8 p. m.			SSE	1·6	0·6 -	-	10	0 -	-	— 1·0 -	-	— 0·6 -
	Midn.			SE b S	3·0	0·8 -	Cir.str. cum.	10	0 -	-	— 1·0 -	-	— 0·6 -
Aug. 11	4 a. m.			SSE	2·4	0·9 -	Cir.str. Fine rain	10	0 -	-	— 0·7 -	-	— 0·3 -
	8 a. m.			SE	2·5	0·9 -	Cir.str. Rain	10	0 -	-	— 1·0 -	-	— 0·6 -
	Noon.	80° 58′	12° 20′	SE	3·0	1·2 -	Str.	10	0 -	-	— 0·9 -	-	— 0·5 -
	4 p. m.			ESE	1·8	1·2 -	Cir.st. cum.	10	0 -	-	— 1·1 -	-	— 0·7 -
	Midn.			ESE	3·3	0·5 -	Cir.str.	10	0 -	-	— 1·3 -	-	— 0·9 -
Aug. 12	4 a. m.			ESE	4·0	0·4 -	-	10	0 -	-	— 1·5 -	-	— 1·1 -
	8 a. m.			E b S	2·7	0·5 -	Str. Snow	10	0 -	-	— 1·0 -	-	— 0·6 -
	Noon.	80° 55′	12° 5′	E b S	3·0		Str. Fog	10	0 -	-	— 1·0 -	-	— 0·6 -
	4 p. m.			E b S	2·7	0·6 -	Str. Rain	10	0 -	-	— 0·5 -	-	— 0·1 -
	8 p. m.			Calm		0·5 -	-	10	0 -	-	— 0·8 -	-	— 0·4 -
	Midn.	80° 42′	11° 30′	SE b E	0·5	0·8 -	-	10	0 -	-	— 0·5 -	-	— 0·1 -

Date. 1896.	Hour.	North Lat.	East Long.	Wind. True Direct.	Wind. Veloc. in m.	Temperature of Air.	Clouds.		Depth in Metres.	Designation of Thermometer.	Temperature of Sea-Surface. Reading.	Instr. Error.	Corrected *t*.	Remarks.
Aug. 13	4 a. m.	80° 27′	12° 16′	E	2·1	1·9 °C.	Str. Fog. Rain	10	0 m.	Sbg. 105?	2·3 ° C.	+ 0·4?	2·7 °C.	
	5 p. m.			NE b N	4·8	2.8 -	Str.	10	0 -	-	4·0 -	-	4·4 -	
	9 p. m.			NNE	6·8	2·5 -	-	10	0 -	-	3·3 -	-	3·7 -	
	Midn.	79° 52′	11° 53′	ENE	3·2	2·4 -	-	10	0 -	-	2·9 -	-	3·3 -	
Aug. 14	4 a. m.	79° 43′	11° 20′	NNE		2·1 -	Fog	10	0 -	-	3·5 -	-	3·9 -	
	4 p. m.			NNW	5·6	1·1 -	Str.	10	0 -	-	2·9 -	-	3·3 -	
	9.15 p. m.			NW	4·5	0·2 -	- sleet	10	0 -	-	2·9 -	-	3·3 -	
Aug. 15	0.15 a. m.	79° 43′	11° 20′	WNW	6·0	— 0·3 -	Str.	10	0 -	-	2·8 -	-	3·2 -	
	4 a. m.			S	1·8	— 0·9 -	Str. Snow	10	0 -	-	2·8 -	-	3·2 -	
	8 a. m.	79° 24′	10° 19′	NW	3·0	0·0 -	Str. Sleet	10	0 -	-	3·0 -	-	3·4 -	
	8 p. m.			NNE	4·7	0·9 -	Str.	10	0 -	-	3·2 -	-	3·6 -	
Aug. 16	0.15 a. m.			NE	2·9	1·0 -	Cu.st. Clearing up	10	0 -	-	3·0 -	-	3·4 -	
	4 a. m.	78° 5′	10° 17′	NE	7·1		-	9	0 -	-	3·5 -	-	3·9 -	
	8 a. m.			NE b E	3·5	2·4 -	-	10	0 -	-	3·6 -	-	4·0 -	
	Noon.			NNE	6·0	1·8 -	-	10	0 -	-	2·8 -	-	3·2 -	
	6 p. m.	77° 23′	12° 11′	NE b N	1·6	1·9 -	Str. Sleet	10	0 -	-	4·2 -	-	4·6 -	
	8 p. m.			NE b N	2·4	1·8 -	Cu.st.	10	0 -	-	3·9 -	-	4·3 -	
	Midn.			NE b E	3·3	2·2 -	-	10	0 -	-	6·5 -	-	6·9 -	
Aug. 17	4 a. m.			N	3·2	2·8 -	0	0	0 -	-	6·0 -	-	6·4 -	
	8 a. m.			NW	5·6	4·1 -	Cu.st.	10	0 -	-	6·0 -	-	6·4 -	
	0.45 p. m.	75° 37′		WNW	7·2	4·9 -	Cir.cu.st.	8	0 -	-	5·5 -	-	5·9 -	
	4.15 p. m.			WNW	10·0	5·2 -	Cu.st.Hail	8	0 -	-	7·3 -	-	7·7 -	
	8.15 p. m.			W b N	13·3	5·2 -	Cu.st.	8	0 -	-	6·9 -	-	7·3 -	
	Midn.			W	8·2	5·3 -	Cir.cu.st.	10	0 -	-	5·9 -	-	6·3 -	
Aug. 18	4 a. m.			WNW	9·7		Cu.st.	10	0 -	-	6·0 -	-	6·4 -	
	8 a. m.			WSW	0·7	5·1 -	-	10	0 -	-	6·9 -	-	7·3 -	
	Noon.	72° 30′	18° 55′	W	5·9	5·5 -	-	10	0 -	-	7·4 -	-	7·8 -	

	4 p. m.			WSW	0·0	6·9 -	-	10	0 -	-	8·6 -	-	9·0 -		
	9 p. m.			S	3·7	7·3 -	Cir.str. cu.st.	10	0 -	-	8·4 -	-	8·8 -		
	Midn.			S	2·1	8·0 -	Cu.st. Some raindrops	10	0 -	-	8·5 -	-	8·9 -		
Aug. 19	4 a. m.			SE b S	2·3	9·1 -	Cum.	8	0 -	-	8·9 -	-	9·3 -		
	8.15 a. m.		19° 21′	SE b E	2·6	10·6 -	Cir.cu.st.	4	0 -	-	9·5 -	-	9·9 -		
	0.15 p. m.	71° 6′		SE b S	2·4	10·8 -	0	0	0 -	-	10·0 -	-	10·4 -		
	4 p. m.			SE b E	1·4	11·0 -	0	0	0 -	-	10·0 -	-	10·4 -		
	8 p. m.			SE b E	1·9	10·7 -	Cum.	8	0 -	-	10·0 -	-	10·4 -		
	Midn.			SE b E	2·6	10·8 -	-	3	0 -	-	10·0 -	-	10·4 -		

B. THE SERIES OF DEEP-SEA TEMPERATURES.

The Deep-Sea Temperatures were taken partly with Pettersson's Water-bottle, partly with Negretti and Zambra's Reversing Thermometers.

The former observations are indicated in the tables by the designation of the thermometer used, viz. *Müll. 7*, *Müll. 6*, or *Grave*. The observations by the reversing thermometers are indicated by N. Z. with a number — 82, etc., which means the Negretti and Zambra Thermometers No. 75682, No. 75684, No. 75680, or No. 75678.

For taking the serial deep-sea temperatures on board the Fram, a special, small sounding-machine was constructed for me by Prof. Pettersson. It consisted of a davit, on which was a wheel with 300 metres of sounding-line, composed of seven thin strands of phosphor-bronze of extra strength. The davit was fixed to the rail of the quarter-deck. The line ran out over a meter-wheel, with registering machinery, hanging under the top of the davit. When the water-bottle was hauled up close under the meter-wheel, it could be swung in on deck by turning the davit, and the temperature-readings and water-samples could then be easily taken. The whole arrangement was very simple and practical.

The depths, during the whole expedition, were measured with the meter-wheel, which was often tested, and always proved very accurate in its indications. At a depth of some hundred metres, the degree of accuracy would be within a metre when a sounding-line of phosphor-bronze or steel was employed, and the soundings were taken from the ice. With a hempen line, the depth could not be measured quite so accurately.

During the voyage of the Fram across the Barents Sea, along the Siberian coast, and during the first months in the ice, all the series of deep-sea temperatures were taken from the ship. Subsequently they were taken from the ice, in the above-mentioned 'water-hole' (see p. 63), which was constantly kept open about 50 metres distant from the port side of the ship. Over this hole was erected a high wooden tripod supporting the meter-wheel, over which the sounding-line was paid out generally by one man from a wheel

placed on a sledge on the ice; if the depths were very considerable, there would be two men or more.

The whole arrangement is seen very well in the illustrations in 'Fram over Polhavet', Vol. I. p. 376 (Christiania, 1897).[1] A Negretti and Zambra reversing thermometer was generally fixed to the line just above the water-bottle (see the illustrations referred to), so that the observations taken by one method were checked by the other. At 50 or 100 metres above this, another Negretti and Zambra thermometer was fixed, for taking the temperature at intervening depths, if *e. g.* the water-bottle was lowered 100 or 200 metres deeper for each sounding.

For taking the serial temperatures in April and May, 1894, a hempen line, 2400 m. long, had to be used, as the bronze line was too short. The hauling-up was then rather slow work, owing to the friction in the water. A sounding-line of flexible steel wire was subsequently made of the thick wire ropes of the Fram. The lower part of this line was made of two strands only, then three strands, while the upper part was made of four strands. The line ran easily through the water, and was always used for the serial temperatures after June, 1894. On June 25th—27th, 1894, the hauling-up with this line took:

from 200 m. 2 min. 15 sec.
- 450 - 8 -
- 500 - 10 -
- 600 - 13 -
- 700 - 16 -
- 1200 - 35 -

To lower the instruments, give them time to assume their permanent indications, and then haul them up again, would require:

at 1000 m. 40 minutes
- 1400 - 65 -

The figures will give an idea of the time generally required for hauling up. On May 13th, 1895, Blessing remarks in the journal that the hauling up from 200 m. took 2 minutes 40 seconds.

For depths below 3000 metres, there was generally not sufficient steel-wire line, and the hempen line had then to be added, which made sounding

[1] 'Farthest North', vol. I, pp. 400 and 482 (London, 1897); and 'In Nacht und Eis', vol. I, p. 372 (Leipzig, 1897).

in these depths somewhat difficult. Another difficulty was that, especially during the winter, the temperature of the air was so low, that the water on the line would freeze and make it very brittle and awkward to handle, as soon as it came out of the water. Sounding was then often accompanied by the risk of losing the instruments and the line; and as we had no great supply of reserve instruments, and very little material for making new lines, the number of the series of deep-sea temperatures had to be reduced to a greater extent than would otherwise have been desirable, in order to be certain that the line should last, and that we should be able to make observations during the whole voyage.

Until March, 1895, the deep-sea temperatures were taken by myself. After that time they were taken by Dr. *H. G. Blessing,* according to my instructions, and in the same manner as before. But as Pettersson's insulated water-bottle was lost on April 6th, 1895, by the breaking of the line, they could afterwards only be taken with the Negretti and Zambra reversing thermometers. As the sounding-line was gradually wearing out, and thus becoming weak, it had to be handled with great care, and the number of deep-sea temperatures had to be reduced in order to spare the line.

TABLE.

The columns of the Table give:

First column, The distinguishing Number of the Series of the Deep-Sea Temperatures.

Second column, The Date of the Observations. In some cases the Hour of the Observations is also given under the Date.

Third column, North Latitude.

Fourth column, Longitude east of Greenwich.

Fifth column, The State of the Atmosphere. In the first line is given the Temperature of the Air, in the second line the true Direction of the Wind and its Velocity per second in metres, and in the third line a Description of the Clouds, and their Amount indicated by numbers, from 0 = clear, to 10 = completely overcast.

Sixth column, Depth in Metres. A thick line under the Number indicates Bottom.

Seventh column, Depth in English Fathoms.

Eighth column, Designations of the Thermometers used. *Müll. 4, Müll. 7, Müll. 6,* and *Grave,* mean the thermometers Frz. Müller 4, 7, 6, and Grave, and the temperature, in these cases, has been taken with Pettersson's insulated Water-Bottle. *Sbg. 114,* etc. means the Söderberg thermometers, and the temperature in these cases has been taken by Scott-Hansen or his assistants, with a glass bottle (see p. 64). The Negretti and Zambra Reversing Thermometers are designated by *N.Z.* and their Numbers by 82, 84, 80, 78, instead of No. 75682, 75684, etc. Where no number is given, the number of the thermometer has not been noted in the journal.

Ninth column, The Temperature-Readings.

Tenth column, The Instrumental Error of the Thermometer for which the Readings have to be corrected; + before the number means that the Correction has to be added to, and — that it has to be taken from, the Reading.

Eleventh column, The Correction by which the Temperature taken with the Insulated Water-Bottle has to be reduced, owing both to the Expansion of the Water-Sample by being hauled up, and to the Rise or Fall of its temperature, caused by its passing through warmer or colder water-strata; see pp. 21 and 24.

Twelfth column, The Temperature of the water *in situ,* Readings being corrected for the instrumental, as well as the above-mentioned Error.

Thirteenth column, The Mean Value of the Determinations of the Temperature *in situ,* where several observations are made at the same depths. For depths below 1000 m. the temperature-readings obtained by Pettersson's Insulated Water-bottle are too uncertain and inaccurate to be considered, and for these depths the temperatures given in the thirteenth column only refer to the determinations made by the Negretti and Zambra Reversing Thermometers.

Fourteenth column, Remarks.

TABLE

SHOWING THE SERIAL DEEP-SEA TEMPERATURES

TAKEN BY **NANSEN FROM JULY 1893 TO DECEMBER 1894** AND BY **BLESSING FROM APRIL 1895 TO APRIL 1896.**

Distinguishing Number of the Temp.-Series.	Date and Hour. 1893.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc	Correct. Temp. *in situ.*	Mean Value.	Remarks.
1	July 22 $9^3/_4$— $11^1/_4$ p. m.	70° 43′	39° 35′	6·0° C. E 3 Fog 10	0	0	Sbg. 25	5·90° C.	— 0·1	0·0	5·80 °C.		
					20	11	Müll. 4	3·93 -	0·0?	0·0	3·93 -		
					40	22	-	3·59 -	0·0	0·0	3·59 -		
					60	33	-	1·60 -	0·0	0·0	1·60 -		
					80	44	-	1·03 -	0·0	0·0	1·03 -		
					100	55	-	0·68 -	0·0	— 0·01	0·67 -		
					150	77·5	-	— 0·56 -	0·0	— 0·02	— 0·58 -		
					200	109	-	— 1·08 -	0·0	— 0·03	— 1·11 -		
2	July 23 9.15 p. m.	71° 3′	43° 31′	4·0° C. NE 3 Fog 10	0	0	Sbg. 25	5·2 -	— 0·1	0·0	5·1 -		
					20	11	Müll. 4	3·68 -	0·0?	0·0	3·68 -		
					40	22	-	1·35 -	0·0	0·0	1·35 -		
					60	33	-	0·56 -	0·0	0·0	0·56 -		
					80	44	-	— 0·42 -	0·0	0·0	— 0·42 -		
					100	55	-	— 0·67 -	0·0	— 0·01	— 0·68 -		
					130	71·5	-	— 0·50 -?	0·0	— 0·02	— 0·52 -		
3	July 24 10 p. m.	71° 17′	48° 14′	3·0° C. NE 3 Fog 10	0	0	Müll. 4	3·69 -	0·0?	0·0	3·69 -		
					20	11	-	2·91 -	0·0	0·0	2·91 -		
					40	22	-	— 1·3 -	0·0	0·0	— 1·3 -		
					60	33	-	— 1·62 -	0·0	0·0	— 1·62 -		
					80	44	-	— 1·7 -	0·0	0·0	— 1·7 -		
					100	55	-	— 1·6[1] -	0·0	— 0·01	— 1·61 -		
					120	66	-	— ?[2] -					
					130	71·5							
4	July 25 6 p. m.	71° 23′	57° 32′	7·0° C. SE b S 8 Fog 10	0	0	Müll. 7	6·90 -	+ 0·02	0·0	6·92 -		
					10	5·5	-	3·84 -	+ 0·02	0·0	3·86 -		
					20	11	-	1·95 -	+ 0·01	0·0	1·96 -		

					30	16·5	-	0·90 -	0·00	0·0	0·90 -	
					40	22	-	— 0·47 -	0·00	0·0	— 0·47 -	
					60	33	-	— 0·98 -	0·00	0·0	— 0·98 -	
					70	38·5	-	— 1·08 -	0·00	0·0	— 1·08 -	
5	July 27 0.20 p. m.	69° 43′	54° 23′	6·0° C.	0	0	Müll. 7	8·36 -	+ 0·03	0·0	8·39 -	
				SE b S 4	5	3	-	4·15 -	+ 0·02	0·0	4·17 -	
				Cir.cum. str. 8	10	5·5	-	2·12 -	+ 0·01	0·0	2·13 -	
					12	6·5	-	0·12 -	0·00	0·0	0·12 -	
					13·5	7·5	-	— 0·70 -	0·00	0·0	— 0·70 -	
					14·5	8	-	— 1·22 -	0·00	0·0	— 1·22 -	
					15	8·2	-	— 1·46 -	— 0·01	0·0	— 1·47 -	
					20	11	-	— 1·52 -	— 0·01	0·0	— 1·53 -	
					30	16·4	-	— 1·6 -	— 0·01	0·0	— 1·61 -	
					40	22	-	— 1·52 -	— 0·01	0·0	— 1·53 -	
					50	27	-	— 1·5 -	— 0·01	0·0	— 1·51 -	
6	July 28 9 p. m.	69° 25′	57° 7′	5·2° C.	0	0	Müll. 7	1·76 -	0·00	0·0	1·76 -	
				W b N 3	5	3	-	— 1·33 -	— 0·01	0·0	— 1·34 -	
				Fog 10	10	5·5	-	— 1·52 -	— 0·01	0·0	— 1·53 -	
					15	8	-	— 1·55 -	— 0·01	0·0	— 1·56 -	
					20	11	-	— 1·63 -	— 0·01	0·0	— 1·64 -	
					22	12	-	— 1·56 -	— 0·01	0·0	— 1·57 -	
7	Aug. 11 Noon.	71° 21′	66° 24′	0·5° C.	0	0	Müll. 7	— 0·22 -	0·00	0·0	— 0·22 -	
				W b N 3	5	3	-	0·32 -	0·00	0·0	0·32 -	
				Fog 10	10	5·5	-	— 0·83 -	0·00	0·0	— 0·83 -	
					15	8	-	— 1·15 -	0·00	0·0	— 1·15 -	
					20	11	-	— 1·05 -	0·00	0·0	— 1·05 -	
					24	13	-	— 1·08 -	0·00	0·0	— 1·08 -	
					26·5	14·5	-					

[1] It is difficult to take the temperature-readings of the cold water-samples from the greater depths accurately, because the upper water-strata inside the water-bottle are warmer than the lower ones, and the distance between the bulb and the zero of the thermometer is so short that the mercury disappears below the lid of the bottle, when the thermometer is duly inserted. For the reading, the thermometer must be drawn up very quickly and must be read off as soon as the top of the mercury becomes visible above the lid; the mercury rises so quickly, however, that errors of a few tenths of a degree may easily occur. (Note in the Journal.)

[2] This temperature was low, but could not be read off accurately, as the mercury in the stem had become separated. (Note in the Journal.

Distinguishing Number of the Temp.-Series.	Date and Hour. 1893.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
8	Oct. 4	78° 38′	135° 0′	— 11·9° C. W b N 8 Str. 10	1370 1465? 1465?	750 800?	N.Z. -	— 0·40° C. (0·18-?)	? ?		— 0·40° C. (0·18 - ?)[1]		[1] The exact depth of this sounding is uncertain, and the observation seems very doubtful.
9	Oct. 9 Noon.	78° 20′	136° 0′	— 14·0° C. N b E 4 Cum.str. 8	0 20 20 40 60 80 100 100 120 145 145	0 11 11 22 33 44 55 55 66 79 79	N.Z. - Müll. 7 N.Z. - - - Müll. 7 - - N.Z.	— 1·6 - — 1·6 - — 1·48 - — 1·6 - — 1·45 - — 1·5 - — 1·3 - — 1·65 - — 1·41 - — 1·25 - — 1·25 -	? ? — 0·02 ? ? ? ? — 0·02 — 0·02 — 0·02 ?	 0·0 0·0 0·0 + 0·01 	— 1·6 - — 1·6 - — 1·50 - — 1·6 - — 1·45 - — 1·5 - — 1·3 - — 1·67 - — 1·43 - — 1·26 - — 1·25 -	1·55° C. 1·49 - 1·26 -	
10	Oct. 12 0.40 p. m.	78° 13′	135° 55′	— 17·3° C. NW b N 6 0 0	90	49	N.Z.	— 1·4 -	?		— 1·4 -		
11	Nov. 9	77° 55′	137° 50′	— 21·0° C. SE b E 6 0 0	0·5 10 10 20 20 30 30 40 40 51 51 53	0·3 5·5 5·5 11 11 16·4 16·4 22 22 28 28 29	Müll. 7 N.Z. Müll. 7 N.Z. Müll. 7 N.Z. Müll. 7 N.Z. Müll. 7 N.Z. Müll. 7	— 1·49 - — 1·48 - — 1·38 - — 1·48 - — 1·43 - — 1·52 - — 1·40 - — 1·60 - — 1·50 - — 1·50 - — 1·60 -	— 0·03 ? — 0·03 ? — 0·03 ? — 0·03 ? — 0·03 ? — 0·03	0·0 0·0 0·0 0·0 0·0 0·0	— 1·52 - — 1·48 - — 1·41 - — 1·48 - — 1·46 - — 1·52 - — 1·43 - — 1·60 - — 1·53 - — 1·50 - — 1·63 -	— 1·52 - 1·45 - 1·47 - 1·48 - 1·57 - 1·57 -	

12	Dec. 21	79° 75′	137° 20′	— 27·8° C. E b N 0 Hazy 10	1500	825	N.Z. 78	— 0·56 -	—0·08?		— 0·64 -	
	1894.											
13	March 1	80° 0′	135° 0′	— 19·5° C. S b E 1 Str. 10	1850	1012	N.Z. 78?	— 0·6 -	—0·10?		— 0·7 -	
14	April 14	80° 12′	133° 50′	— 18·0° C. E b N 2 Snow 10	0	0	Müll. 7	— 1·56 -	— 0·06	0·0	— 1·62 -	— 1·62 -
					0·5	0·3	-	— 1·56 -	— 0·06	0·0	— 1·62 -	
					20	11	Müll. 7	— 1·60 -	— 0·06	0·0	— 1·66 -	— 1·66 -
							N.Z. 82	— 1·53 -	— 0·12		— 1·65 -	
					40	22	Müll. 7	— 1·70 -	— 0·06	0·0	— 1·76 -	— 1·77 -
							N.Z. 82	— 1·65 -	— 0·12		— 1·77 -	
					60	33	Müll. 7	— 1·85 -	— 0·06	0·0	— 1·91 -	— 1·81 -
							N.Z. 82	— 1·67 -	— 0·12		— 1·79 -	
							N.Z. 84	— 1·6 -	— 0·12		— 1·72 -	
	April 15	80° 11·1′	133° 36′	— 18·0° C. S 3 Cum.str. 10	80	44	Müll. 7	— 1·75 -	— 0·06	0·0	— 1·81 -	— 1·79 -
							N.Z. 82	— 1·61 -	— 0·12		— 1·73 -	
							N.Z. 84	— 1·72 -	— 0·12		— 1·84 -	
					100	55	Müll. 7	— 1·63 -	— 0·06	+ 0·01	— 1·68 -	— 1·67 -
							N.Z. 82	— 1·60 -	— 0·12		— 1·72 -	
							N.Z. 84	— 1·50 -	— 0·12		— 1·62 -	
					120	66	Müll. 7	— 1·55 -	— 0·06	+ 0·02	— 1·59 -	— 1·56 -
							N.Z. 82	— 1·44 -	— 0·12		— 1·56 -	
							N.Z. 84	— 1·43 -	— 0·12		— 1·55 -	
					140	77	Müll. 7	— 1·25 -	— 0·05	+ 0·03	— 1·27 -	— 1·31 -
							N.Z. 82	— 1·22 -	— 0·12		— 1·34 -	
							N.Z. 84	— 1·20 -	— 0·12		— 1·32 -	
					160	87	Müll. 7	— 0·95 -	— 0·05	+ 0·06	— 0·94 -	— 0·93 -
							N.Z. 82	— 0·8 -	— 0·12		— 0·92 -	
					180	98	Müll. 7	— 0·45 -	— 0·05	+ 0·11	— 0·39 -	— 0·38 -
							N.Z. 82	— 0·27 -	— 0·12		— 0·39 -	
							N.Z. 84	— 0·25 -	— 0·12		— 0·37 -	

Distinguishing Number of the Temp.-Series.	Date and Hour. 1894.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
14	April 15	80° 11·1′	133° 36′	— 17° C. S 3 Cum.str. 10	200	109	Müll. 7	— 0·38° C.	— 0·05	+ 0·13	— 0·30° C.	— 0·23° C.	
							N.Z. 82	— 0·04 -	— 0·12		— 0·16 -		
	April 23	80° 27·6′	131° 14′	— 20° C. SE 4 0 0	200	109	N.Z. 84	— 0·3 -	— 0·12		— 0·42 -	— 0·42 -	
	April 15	80° 11·1′	133° 66′	— 17° C. S 3 Cum.str. 10	230	126	N.Z. 84	0·25 -	— 0·12		0·13 -	0·13 -	
					250	137	Müll. 7	0·30 -	— 0·06	+ 0·18	0·42 -	0·43 -	
							N.Z. 82	0·55 -	— 0·12		0·43 -		
	April 21	80° 28·1′	131° 8′	— 20·0° C. E 4 Cir. 8	250	137	Müll. 7	— 0·16 -[1]	— 0·05	+ 0·18	— 0·03 -	— 0·02 -	[1] In the original journal there is written + before this temperature, but with a query. It should evidently be —.
							N.Z. 82	0·12 -	— 0·12		0·00 -		
	April 23	80° 27·6′	131° 14′	— 20·0° C. SE 4 0 0	250	137	Müll. 7	— 0·10 -	— 0·05	+ 0·18	0·03 -	0·00 -	
							N.Z. 82	0·09 -	— 0·12		— 0·03 -		
							N.Z. 84[1]	0·39[1] -	— 0·12		0·27 -	0·27 -	
							N.Z. 84	0·19 -	— 0·12		0·07 -	0·07 -	
					300	164	Müll. 7	0·00 -	— 0·05	+ 0·21	0·16 -	0·17 -	
							N.Z. 82	0·30 -	— 0·12		0·18 -		
							Müll. 7	0·00 -	— 0·05	+ 0·21	0·16 -	0·18 -	
							N.Z. 82	0·32 -	— 0·12		0·20 -		
					350	191	N.Z. 84	0·28 -	— 0·12		0·16 -	0·16 -	
					400	219	N.Z. 82	0·38 -	— 0·12		0·26 -	0·27 -	
							Müll. 7	0·10 -	— 0·05	+ 0·23	0·28 -		
					500	273	N.Z. 82	0·375 -	— 0·12		0·26 -	0·27 -	
							Müll. 7	0·10 -	— 0·05	+ 0·23	0·28 -		
					550	301	N.Z. 84	0·22 -	— 0·12		0·10 -	0·10 -	
					600	328	N.Z. 82	0·20 -	— 0·12		0·08 -	0·06 -	
							Müll. 7	— 0·10 -	— 0·05	+ 0·18	0·03 -		

April 24	80° 29·5′	131° 30′	— 19·0° C. SE b S 5 0 0	700	383	N.Z. 84	0·1 -	— 0·12		— 0·02 -	— 0.02 -	
				800	437	N.Z. 82 Müll. 7	— 0·01 - — 0·15 -	— 0·12 — 0·05	+ 0·10	— 0·13 - — 0·10 -	— 0·11 -	
				900	492	N.Z. 84	0·0 -	— 0·12		— 0·12 -	— 0·12 -	
				1000	547	N.Z. 82 Müll. 7	— 0·09 - 0·05? -	— 0·12		— 0·21 -	— 0·21 -	
				1100	601	N.Z. 84	— 0·2 -	— 0·12		— 0·32 -	— 0·32 -	
				1200	656	N.Z. 82 Müll. 7	— 0·28 - — 0·36 -	— 0·12 — 0·05	— 0·06	— 0·40 - (— 0·47 -)	— 0·40 -	
				1300	711	N.Z. 84	— 0·38 -	— 0·12		— 0·50 -	— 0·50 -	
				1400	766	N.Z. 82 Grave	— 0·38 - — 0·1 [2] -	— 0·12 — 0·22	— 0·12	— 0·50 - (— 0·44 -)	— 0·51 -	
April 26	80° 34·6′	131° 34′	— 18·0° C. S b W 4 Cum. 10			N.Z. 82 Müll. 7	— 0·40 - — 0·38 -	— 0·12 — 0·05	— 0·12	— 0·52 - (— 0·55 -)		
				1500	820	N.Z. 84	— 0·48 -	— 0·12		— 0·60 -	— 0·60 -	
April 24	80° 29·1′	131° 25′	SE b S 5 0 0			-	— 0·3 -	— 0·12		— 0·42? -		
				1600	875	N.Z. 82 Grave	— 0·54 - — 0·2 [2] -	— 0·12 — 0·22	— 0·19	— 0·66 - (— 0·61 -)	— 0·66 -	
April 26	80° 34·6′	131° 34′	— 18·0° C. S b W 4 Cum. 10			N.Z. 82 Müll. 7	0·3 [3] - — 0·4 -	— 0·05	— 0·19	(— 0·64 -)		
April 25	80° 32′	131° 30′	— 17·0° C. SSE 5 Str. 10	1700	930	N.Z. 84	— 0·62 -	— 0·12		— 0·74 -	— 0·74 -	
				1800	984	N.Z. 82 Müll. 7	— 0·63 - — 0·40 -	— 0·12 — 0·05	— 0·25	— 0·75 - (— 0·70 -)	— 0·75 -	

[1] As this temperature-reading seemed to me not to agree very well with the others from the same depth, a new observation was taken giving 0·19° C. This series of observations from the same depths shows what remarkable variations of temperature there are in the strata of about 250 metres, while at 300 metres we get the same readings by two different observations.

[2] Ekman's water-bottle was used for both observations.

[3] The thermometer indicated thus, but there has evidently been some irregularity in the breaking off of the mercury column.

Distinguishing Number of the Temp.-Series.	Date and Hour. 1894.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
14	April 25	80° 32′	131° 30′	— 17·0° C. SSE 5 Str. 10	1900	1039	N.Z. 84	— 0·69° C.	— 0·12		— 0·81° C.	— 0·81° C.	
					2000	1094	N.Z. 82	— 0·71 -	— 0·12		— 0·83 -	— 0·83 -	The closing of the stop-cock before the water-bottle went down had been forgotten.
							Müll. 7	— 0·80 -					
					2200	1203	N.Z. 82	— 0·75 -	— 0·12		— 0·87 -	— 0·87 -	
							Müll. 7	0·25? -					
					2400	1312	N.Z. 82	— 0·78 -	— 0·12		— 0·90 -	— 0·90 -	
							Müll. 7	— 0·6 -	— 0·05	— 0·40	(— 1·05 -)		
15	May 22	81° 24′	125° 0′	— 5·4° C. — 8·4 - E b S 8 Cum. 10	0·3	0·16	Grave	— 1·55 -	— 0·21	0·0	— 1·76 -	— 1·71 -	
							Müll. 7	— 1·62 -	— 0·06	0·0	— 1·68 -		
							N.Z. 82	— 1·6 -	— 0·08		— 1·68 -		
					10	5	Grave	— 1·45 -	— 0·21	0·0	— 1·66 -	— 1·67 -	
							Müll. 7	— 1·62 -	— 0·06	0·0	— 1·68 -		
							N.Z. 82	— 1·6 -	— 0·08		— 1·68 -		
					20	11	Grave	— 1·44 -	— 0·21	0·0	— 1·65 -	— 1·68 -	
							Müll. 7	— 1·64 -	— 0·06	0·0	— 1·70 -		
							N.Z. 82	— 1·6 -	— 0·08		— 1·68 -		
					30	16	N.Z. 84	— 1·55 -	— 0·08		— 1·63 -	— 1·63 -	
					40	22	Grave	— 1·45 -	— 0·21	0·0	— 1·66 -	— 1·69 -	
							Müll. 7	— 1·65 -	— 0·06	0·0	— 1·71 -		
							N.Z. 82	— 1·62 -	— 0·08		— 1·70 -		
					50	27	N.Z. 84	— 1·65 -	— 0·08		— 1·73 -	— 1·73 -	
					60	33	Müll. 7	— 1·71 -	— 0·06	0·0	— 1·77 -	— 1·75 -	
							N.Z. 82	— 1·65 -	— 0·08		— 1·73 -		
					70	38	N.Z. 84	— 1·64 -	— 0·08		— 1·72 -	— 1·72 -	
					80	44	Müll. 7	— 1·71 -	— 0·06	0·0	— 1·77 -	— 1·75 -	
							N.Z. 82	— 1·65 -	— 0·08		— 1·73 -		

				90	49	N.Z. 84	— 1·60 -	— 0·08		— 1·68 -	— 1·68 -	
				100	55	Müll. 7	— 1·58 -	— 0·06	0·0	— 1·64 -	— 1·62 -	
						N.Z. 82	— 1·52 -	— 0·08		— 1·60 -		
				110	60	N.Z. 84	— 1·46 -	— 0·08		— 1·54 -	— 1·54 -	
				120	66	Müll. 7	— 1·43 -	— 0·06	+ 0·1	— 1·48 -	— 1·45 -	
						N.Z. 82	— 1·34 -	— 0·08		— 1·42 -		
				140	77	N.Z. 84	— 1·34 -	— 0·08		— 1·42 -	— 1·42 -	
				160	87	Müll. 7	— 1·12 -	— 0·05	+ 0·02	— 1·15 -	— 1·15 -	
						N.Z. 82	— 1·10 -	— 0·04		— 1·14 -		
				180	98	N.Z. 84	— 0·48 -	— 0·08		— 0·56 -	— 0·56 -	
				200	109	Müll. 7	— 0·38 -	— 0·05	+ 0·09	— 0·34 -	— 0·33 -	
						N.Z. 82	— 0·24 -	— 0·08		— 0·32 -		
May 23	81° 26·8′	124° 0′	— 5·0° C.	220	120	N.Z. 84	— 0·11 -	— 0·08		— 0·19 -	— 0·19 -	
			E b S 7									
			Cum. 10	240	131	Müll. 7	— 0·16 -	— 0·05	+ 0·12	— 0·09 -	— 0·10 -	
						N.Z. 82	— 0·02 -	— 0·08		— 0·10 -		
				280	153	N.Z. 84	0·23 -	— 0·08		0·15 -	0·15 -	
				300	164	Müll. 7	0·10 -	— 0·05	+ 0·14	0·19 -	0·16 -	
						N.Z. 82	0·2 -	— 0·08		0·12 -		
				400	219	Müll. 7	0·18 -	— 0·05	+ 0·18	0·31 -	0·32 -	
						N.Z. 82	0·40 -	— 0·08		0·32 -		
				500	273	N.Z. 82	0·38 -	— 0·08		0·30 -	0·30 -	
						Müll. 7	— 0·10 -	— 0·05	+ 0·18	0·03 - ?		
				550	301	N.Z. 84	0·24 -	— 0·08		0·16 -	0·16 -	
				600	328	N.Z. 82	0·22 -	— 0·08		0·14 -	0·12 -	[1] Indicated a little later — 0·15° C.
						Müll. 7	0·02[1] -	— 0·06	+ 0·14	0·10 -		

Distinguishing Number of the Temp.-Series.	Date and Hour. 1894.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
15	May 24	81° 32·6′	123° 2′	— 1·0° C. ESE 7 Str. 10	650	355	N.Z. 84	0·18° C.	— 0·08		0·10° C.	0·10° C.	
					700	383	N.Z. 82	0·12 -	— 0·08		0·04 -	0·03 -	
							Grave	0·12 -	— 0·22	+ 0·11	0·01 -		
					750	410	N.Z. 84	0·04 -	— 0·08		— 0·04 -	— 0·04 -	
					800	437	N.Z. 82	0·01 -	— 0·08		— 0·07 -	— 0·08 -	
							Grave	0·03 -	— 0·22	+ 0·09	— 0·10 -		
					850	465	N.Z. 84	— 0·01 -	— 0·08		— 0·09 -	— 0·09 -	
					900	492	N.Z. 82	— 0·03 -	— 0·08		— 0·11 -	— 0·13 -	
							Grave	0·00 -	— 0·22	+ 0·07	— 0·15 -		
					950	519	N.Z. 84	— 0·06 -	— 0·08		— 0·14 -	— 0·14 -	
					1000	547	N.Z. 82	— 0·1 -	— 0·08		— 0·18 -	— 0·18 -	
							Grave	0·00 -	— 0·22	+ 0·05	— 0·17 -		
					1050	574	N.Z. 84	— 0·22 -	— 0·08		— 0·30 -	— 0·30 -	
					1200	656	N.Z. 82	— 0·27 -	— 0·08		— 0·35 -	— 0·35 -	
							Grave	— 0·04 -	— 0·22	— 0·07	(— 0·33 -)		
					1300	711	N.Z. 84	— 0·41 -	— 0·08		— 0·49 -	— 0·49 -	
					1400	766	N.Z. 82	— 0·41 -	— 0·08		— 0·49 -	— 0·49 -	
							Grave	— 0·02 -	— 0·22	— 0·16	(— 0·40 -)		
	May 25	81° 31′	123° 2′	— 5° C. EbS 6 Cir.str. 10	1500	820	N.Z. 84	— 0·47 -	— 0·08		— 0·55 -	— 0·55 -	
					1600	875	N.Z. 82	[1]					[1] Indication spoilt by an accident.
							Grave	— 0·21 -	— 0·22	— 0·23	(— 0·66 -)		
					1700	930	N.Z. 84	— 0·60 -	— 0·08		— 0·68 -	— 0·68	
					1800	984	N.Z. 82	— 0·63 -	— 0·08		— 0·71 -	— 0·71 -	
							Grave	— 0·22 -	— 0·22	— 0·32	(— 0·76 -)		

					1900	1039	N.Z. 84	— 0·64 -	— 0·08		— 0·72 -	— 0·72 -	
					2000	1094	N.Z. 82	— 0·70 -	— 0·08		— 0·78 -	— 0·78 -	
							Grave	— 0·2 -	— 0·22	— 0·38	(— 0·80 -)		
					2100	1148	N.Z. 84	— 0·74 -	— 0·08		— 0·82 -	— 0·82 -	
					2200	1203	N.Z. 82	— 0·74 -	— 0·08		— 0·82 -	— 0·82 -	
							Grave	— 0·2 -	— 0·22	— 0·44	(— 0·86 -)		
	May 26	81° 30·6′	123° 0′	— 5·0° C. NE b E 6 0 0	2300	1258	N.Z. 84	— 0·78 -	— 0·08		— 0·86 -	— 0·86 -	
					2400	1312	N.Z. 82	0·2 [2] -					[2] There has evidently been some irregularity in the breaking off of the mercury column.
							Grave	— 0·32 -	— 0·22	— 0·48	(— 1·02 -)		
16	June 26 ca. 8 p. m.	81° 37′	121° 6′	— 0·9° C. NW b W 4 Cum.str. 10	0·15	0·08	Grave	0·55 -	— 0·22	0·0	0·33 -	0·33 -	
					0·25	0·13	N.Z. 82	0·65 -	— 0·07		0·58 -	0·58 -	
					5	3	Grave	— 1·40 -	— 0·21	0·0	— 1·61 -	— 1·61 -	
							N.Z. 82	— 1·54 -	— 0·07		— 1·61 -		
	June 22	81° 46′	121° 40′	0·85— — 0·6° C. NW b W 6 Str. 10	10	5	Müll. 7	— 1·52 -	— 0·06	0·0	— 1·58 -	— 1·63 -	
							N.Z. 82	— 1·6 -	— 0·07		— 1·67 -		
							Grave	— 1·30 -	— 0·21	0·0	(— 1·51 -) [3]		
	June 23	81° 41·7′	121° 30′	0·4° C. N b W 6 Cir.str. 10			Grave	— 1·42 -	— 0·21	0·0	— 1·63 -	— 1·63 -	
							N.Z. 82	— 1·56 -	— 0·07		— 1·63 -		
	June 22	81° 46′	121° 40′	0.85— — 0·6° C. NW b W 6 Str. 10	20	11	Müll. 7	— 1·50 -	— 0·06	0·0	— 1·56 -	— 1·60 -	
							N.Z. 82	— 1·56 -	— 0·07		— 1·63 -		
							Grave	— 1·32 -	— 0·21	0·0	(— 1·53 -) [3]		
	June 23	81° 41·7′	121° 30′	0·4° C. N b W 6 Cir.str. 10			Grave	— 1·40 -	— 0·21	0·0	— 1·61 -	— 1·61 -	
							N.Z. 82	— 1·54 -	— 0·07		— 1·61 -		

[3] These temperature readings were taken after those of Müller No. 7, while the water-bottle was all the time hanging in the air. The determinations cannot therefore be expected to be very accurate, as the temperature of the water-sample in the bottle has evidently been raised by the surrounding air, and by the insertion of thermometers.

Distinguishing Number of the Temp.-Series.	Date and Hour. 1894.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc	Correct. Temp. *in situ.*	Mean Value.	Remarks.
16	June 26 ca. 8 p. m.	81° 37′	121° 6′	— 0·0° C. NW b W 4 Cum.str. 10	30	16	Müll. 7	— 1·50° C.	— 0·06	0·0	— 1·56° C.	— 1·60° C.	
							Grave	— 1·36 -	— 0·21	0·0	— 1·57 -		
							N.Z. 82	— 1·6 -	— 0·07		— 1·67 -		
					40	22	Müll. 7	— 1·50 -	— 0·06	0·0	— 1·56 -	— 1·63 -	
							N.Z. 82	— 1·62 -	— 0·07		— 1·69 -		
					50	28	Grave	— 1·51 -	— 0·21	0·0	— 1·72 -	— 1·72 -	
							N.Z. 82	— 1·64 -	— 0·07		— 1·71 -		
	June 22	81° 46′	121° 40′	0.85— — 0·6° C. NW b W 6 Str. 10	60	33	Grave	— 1·56 -	— 0·21	0·0	— 1·77 -	— 1·79 -	
							N.Z. 82	— 1·73 -	— 0·07		— 1·80 -		
	June 23	81° 41·7′	121° 30′	0·4° C. N b W 6 Cir.str. 10			Grave	— 1·54 -	— 0·21	0·0	— 1·75 -	— 1·74 -	
							N.Z. 82	— 1·66 -	— 0·07		— 1·73 -		
					80	44	Grave	— 1·48 -	— 0·21	0·0	— 1·69 -	— 1·69 -	
							N.Z. 82	— 1·62 -	— 0·07		— 1·69 -		
					100	55	Grave	— 1·36 -	— 0·21	0·0	— 1·57 -	— 1·59 -	
							N.Z. 82	— 1·53 -	— 0·07		— 1·60 -		
					120	66	Grave	— 1·12 -	— 0·22	0·0	— 1·34 -	— 1·33 -	
							N.Z. 82	— 1·24 -	— 0·07		— 1·31 -		
	June 25	81° 39·2′	121° 0′	— 0·8° C. NW b N 5 Cir.cum. 10	140	77	Grave	— 0·76 -	— 0·22	0·0	— 0·98 -	— 0·98 -	
							N.Z. 82	— 0·90 -	— 0·07		— 0·97 -		
					160	87	Grave	— 0·48 -	— 0·22	+ 0·01	— 0·69 -	— 0·69 -	
							N.Z. 82	— 0·62 -	— 0·07		— 0·69 -		
					180	98	Grave	— 0·18 -	— 0·22	+ 0·02	— 0·38 -	— 0·37 -	
							N.Z. 82	— 0·28 -	— 0·07		— 0·35 -		
					200	109	Grave	— 0·07 -	— 0·22	+ 0·02	— 0·27 -	— 0·28 -	The hauling up took 2 minutes 15 seconds.
							N.Z. 82	— 0·22 -	— 0·07		— 0·29 -		

					225	123	Grave N.Z. 82	0·14 - — 0·01 -	— 0·22 — 0·07	+ 0·03	— 0·05° C. — 0·08 -	— 0·07° C.
					250	137	Grave N.Z. 82	0·65 - 0·52 -	— 0·22 — 0·07	+ 0·04	0·47 - 0·45 -	0·46 -
							Grave N.Z. 82	0·64 - 0·53 -	— 0·22 — 0·07	+ 0·04	0·46 - 0·46 -	0·46 - [1]
					275	150	Grave N.Z. 82	0·43 - 0·33 -	— 0·22 — 0·07	+ 0·05	0·26 - 0·26 -	0·26 -
							Grave N.Z. 82	0·44 - 0·33 -	— 0·22 — 0·07	+ 0·05	0·27 - 0·26 -	0·265 - [1]
					300	164	Grave N.Z. 82	0·65 - 0·58 -	— 0·22 — 0·07	+ 0·06	0·49 - 0·51 -	0·50 -
					325	178	Grave N.Z. 82	0·66 - 0·60 -	— 0·22 — 0·07	+ 0·06	0·50 - 0·53 -	0·52 -
June 26 9.30 a. m.	81° 37′	121° 6′	— 1·5° C. NW b N 5 Cum.str. 10		325	178	Grave N.Z. 82	0·45 - 0·35 -	— 0·22 — 0·07	+ 0·06	0·29 - 0·28 -	0·29 -
					350	191	Grave N.Z. 82	0·47 - 0·40 -	— 0·22 — 0·07	+ 0·07	0·32 - 0·33 -	0·33 -
					375	205	Grave N.Z. 82	0·48 - 0·41 -	— 0·22 — 0·07	+ 0·07	0·33 - 0·34 -	0·34 -
					400	219	Grave N.Z. 82	0·49 - 0·43 -	— 0·22 — 0·07	+ 0·07	0·34 - 0·36 -	0·35 -
					425	232	N.Z. 82 Grave	0·44 - 0·49 -	— 0·07 — 0·22	0·0 + 0·07	0·37 - 0·34 -	0·36 -
					450	246	N.Z. 82 Grave	0·43 - 0·52 -	— 0·07 — 0·22	0·0 + 0·07	0·36 - 0·37 -	0·37 - Hauling up took 8 minutes.

[1] At both depths the soundings were repeated for the sake of verification. It is seen that the determinations of the temperature *in situ* agree very well, and this seems to indicate a high degree of accuracy.

Distinguishing Number of the Temp.-Series.	Date and Hour. 1894.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
16	June 26	81° 37′	121° 6′	— 1·5° C. NW b N 5 Cum.str. 10	500	273	N.Z. 82	0·35° C.	— 0·07	0·0	0·28° C.	0·27° C.	Hauling up took 10 minutes.
							Grave	0·40 -	— 0·22	+ 0·07	0·25 -		
					550	301	N.Z. 82	0·29 -	— 0·07	0·0	0·22 -	0·23 -	
							Grave	0·39 -	— 0·22	+ 0·07	0·24 -		
					600	328	N.Z. 82	0·20 -	— 0·07	0·0	0·13 -	0·14 -	Hauling up took 13 minutes.
							Grave	0·33 -	— 0·22	+ 0·05	0·16 -		
					700	383	N.Z. 82	0·15 -	— 0·07	0·0	0·08 -	0·10 -	Hauling up took 16 minutes.
							Grave	0 30 -	— 0·22	+ 0·04	0·12 -		
	June 27 11.50 a. m.	81° 36′	121° 12′	0·3° C. SW b W 7 Str. 10	800	437	N.Z. 82	0·05 -	— 0·07		— 0·02 -	— 0·02 -	
							Grave	0·18 -	— 0·22	+ 0·03	— 0·01 -		
	0·35 p. m.				1000	547	N.Z. 82	— 0·07 -	— 0·07		— 0·14 -	— 0·13 -	
							Grave	0·1 -	— 0·22	0·0	— 0·12 -		
	3.10 p. m.			0·7° C.	1200	656	N.Z. 82	— 0·3 -	— 0·07		— 0·37 -	— 0·37 -	Hauling up took 35 minutes.
							Grave	0·0 -	— 0·22	—0·08?	(— 0·30 -)		
	4.20 p. m.			0·9° C. SW b W 4 Str. 9	1400	766	N.Z. 82	— 0·40 -	— 0·07		— 0·47 -	— 0·47 -	
					1600	875	N.Z. 82	— 0·54 -	— 0·07		— 0·61 -	— 0·61 -	
							Grave	— 0·14 -	— 0·22	—0·18?	(— 0·54 -)		
16 a	June 26	81° 37′	121° 6′	— 1·0° C.	225	123	Grave	0·12 -	— 0·22	+ 0·03	— 0·07 -	— 0·07 -	
							N.Z. 82	0·01 -	— 0·07		— 0·06 -		
					250	137	Grave	0·32 -	— 0·22	+ 0·04	0·14 -	0·13 -	
							N.Z. 82	0·19 -	— 0·07		0·12 -		
					275	150	Grave	0·34 -	— 0·22	+ 0·05	0·17 -	0·17 -	
							N.Z. 82	0·23 -	— 0·07		0·16 -		
					280	153	Grave	0·30 -	— 0·22	+ 0·05	0·13 -	0·13 -	
							N.Z. 82	0·20 -	— 0·07		0·13 -		

					290	159	Grave N.Z. 82	0·68 - 0·58 -	— 0·22 — 0·07	+ 0·06	0·52 - 0·51 -	0·52 -	
					300	164	Grave N.Z. 82	0·68 - 0·57 -	— 0·22 — 0·07	+ 0·06	0·52 - 0·50 -	0·51 -	
	7.30 p. m.				310	170	Grave N.Z. 82	0·70 - 0·60 -	— 0·22 — 0·07	+ 0·06	0·54 - 0·53 -	0·54 -	
					325	178	Grave N.Z. 82	0·68 - 0·58 -	— 0·22 — 0·07	+ 0·06	0·52 - 0·51 -	0·52 -	
16 b	June 27 10 a. m.	81° 36′	121° 12′	0·0° C. SW b W 5 Cum.str. 10	225	123	Grave N.Z. 82	0·20 - 0·05 -	— 0·22 — 0·07	+ 0·03	0·01 - — 0·02 -	— 0·01 -	
	10.10 a. m.				250	137	Grave N.Z. 82	0·47 - 0·32 -	— 0·22 — 0·07	+ 0·04	0·29 - 0·25 -	0·27 -	
	10.25 a. m.				275	150	Grave N.Z. 82	0·40 - 0·28 -	— 0·22 — 0·07	+ 0·05	0·23 - 0·21 -	0·22 -	
	10.40 a. m.				300	164	Grave N.Z. 82	0·52 - 0·35 -	— 0·22 — 0·07	+ 0·06	0·36 - 0·28 -	0·32 -	
	11 a. m.			0·2° C.	325	178	Grave N.Z. 82	0·56 - 0·40 -	— 0·22 — 0·07	+ 0·06	0·40 - 0·33 -	0·37 -	
	11.20 a. m.				350	191	Grave N.Z. 82	0·53 - 0·39 -	— 0·22 — 0·07	+ 0·07	0·38 - 0·32 -	0·35 -	
17	July 11	81° 18·9′	124° 38′	1·0° C. S 3 Cir. 10	0	0	Grave	0·4 -	— 0·22	0·0	0·18 -		At a depth of 2·3 m. a thin crust of ice (about 3 cm. thick) extended along the margin of the water-hole, and towards its centre. It was quite soft, and easy to penetrate with a rod.
					1	0·55	-	0·36 -	— 0·22	0·0	0·14 -		
					2	1·09	-	0·30 -	— 0·22	0·0	0·08 -		
					3	1·64	-	— 1·37 -	— 0·21	0·0	— 1·58 -		
					5	2·73	-	— 1·41 -	— 0·21	0·0	— 1·62 -		
					10	5·47	-	— 1·40 -	— 0·21	0·0	— 1·61 -		
18	Aug. 13 2.30— 6 p. m.	81° 4·4′	127° 55′	0·5° C. NE b E 3 Strat. 10	0	0	Grave	1·02 -	— 0·23	0·0	0·79 -		With Pettersson's water-bottle in water-hole.
					0	0	Sbg. 114	0·75 -	+ 0·05	0·0	0·80 -		With glass bottle in water-lane.
					1	0·53	-	0·6 -	+ 0·05	0·0	0·65 -		— — — — —
					1·6	0·87	-	0·02 -	+ 0·05	0·0	0·07 -		— — — — —
					1·65	0·90	-	— 0·43 -	+ 0·05	0·0	— 0·38 -		— — — — —

Distinguishing Number of the Temp.-Series.	Date and Hour. 1894.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
18	Aug. 13 2.30— 6 p. m.	81° 4·4′	127° 55′	0·5° C. NE b E 3 Strat. 10	2	1·09	Grave	— 1·32° C.	— 0·21	0·0	— 1·53° C.	— 1·39° C.	With Pettersson's water-bottle in water-hole.
					2	1·09	Sbg. 114	— 1·30 -	+ 0·05	0·0	— 1·25 -		With glass bottle in water-lane.
					2·5	1·37	-	— 1·40 -	+ 0·05	0·0	— 1·35 -		— — — — —
					3	1·64	-	— 1·50 -	+ 0·05	0·0	— 1·45 -		— — — — —
					5	2·73	Grave	— 1·33 -	— 0·21	0·0	— 1·54 -		With Pettersson's water-bottle in water-hole.
					10	5·47	-	— 1·33 -	— 0·21	0·0	— 1·54 -		
					20	11	-	— 1·33 -	— 0·21	0·0	— 1·54 -		
					30	16	-	— 1·38 -	— 0·21	0·0	— 1·59 -		
					40	22	-	— 1·50 -	— 0·21	0·0	— 1·71 -		
					50	28	-	— 1·53 -	— 0·21	0·0	— 1·74 -		
					60	33	-	— 1·50 -	— 0·21	0·0	— 1·71 -		
					80	44	-	— 1·50 -	— 0·21	0·0	— 1·71 -		
					100	55	-	— 1·40 -	— 0·21	0·0	— 1·61 -		
					120	66	-	— 1·24 -	— 0·22	0·0	— 1·46 -		
					140	77	-	— 0·97 -	— 0·22	+ 0·01	— 1·18 -		
					160	87	-	— 0·58 -	— 0·22	+ 0·01	— 0·79 -		
					180	98	-	— 0·31 -	— 0·22	+ 0·01	— 0·52 -		
					200	109	-	— 0·03 -	— 0·22	+ 0·02	— 0·23 -		
					220	120	-	0·19 -	— 0·22	+ 0·03	0·00 -		
					240	131	-	0·20 -	— 0·22	+ 0·03	0·01 -		
					260	142	-	0·34 -	— 0·22	+ 0·04	0·16 -		
					280	153	-	0·42 -	— 0·22	+ 0·05	0·25 -		
					300	164	-	0·34 -	— 0·22	+ 0·06	0·18 -		
	Aug. 14	81° 5·6′	127° 57′		300	164	-	0·41 -	— 0·22	+ 0·06	0·25 -		
	Aug. 13	81° 4·4′	127° 55′		325	178	-	0·49 -	— 0·22	+ 0·06	0·33 -		
					350	191	-	0·44 -	— 0·22	+ 0·07	0·29 -		
	Aug. 14	81° 5·6′	127° 57′	— 0·3° C. E b S 3 Cum.str. 10	350	191	Grave	0·43 -	— 0·22	+ 0·07	0·28 -	0·27 -	
							N.Z. 82	0·30 -	— 0·04		0·26 -		

				375	205	Grave	0·43 -	— 0·22	+ 0·07	0·28 -	0·27 -
						N.Z. 82	0·30 -	— 0·04		0·26 -	
				400	219	Grave	0·48 -	— 0·22	+ 0·07	0·33 -	0·32 -
						N.Z. 82	0·35 -	— 0·04		0.31 -	
				450	246	N.Z. 82	0·36 -	— 0·04		0·32 -	0·32 -
						Grave	0·47 -	— 0·22	+ 0·07	0·32 -	
				500	273	N.Z. 82	0·34 -	— 0·04		0·30 -	0·30 -
						Grave	0·45 -	— 0·22	+ 0·07	0·30 -	
				550	300	N.Z. 82	0·22 -	— 0·04		0·18 -	0·19 -
						Grave	0·35 -	— 0·22	+ 0.06	0·19 -	
				600	328	N.Z. 82	0·20 -	— 0·04		0·16 -	0·16 -
						Grave	0·32 -	— 0·22	+ 0·05	0·15 -	
				650	355	N.Z. 82	0·18 -	— 0·04		0·14 -	0·14 -
						Grave	0·32 -	— 0·22	+ 0·04	0·14 -	
				700	383	N.Z. 82	0·14 -	— 0·04		0·10 -	0·10 -
						Grave	0·28 -	— 0·22	+ 0·04	0·10 -	
				800	437	N.Z. 82	0·07 -	— 0·04		0·03 -	0·02 -
						Grave	0·20 -	— 0·22	+ 0·03	0·01 -	
				900	492	N.Z. 82	— 0·04 -	— 0·04		— 0·08 -	— 0·09 -
						Grave	0·10 -	— 0·22	+ 0·02	— 0·10 -	
				1000	547	N.Z. 82	— 0·10 -	— 0·04		— 0·14 -	— 0·14 -
						Grave	0·08 -	— 0·22	0·00	— 0·14 -	
Aug. 15	81° 6·6′	127° 49′	0·5° C. SSW 2 Cum.str. 10	1200	656	N.Z. 82	— 0·28 -	— 0·04		— 0·32 -	
				1300	711	N.Z. 84[1]	— 0·30 -	— 0·03		— 0·33 -	
				1400	766	N.Z. 82	— 0·34 -	— 0·04		— 0·38 -	
				1500	820	N.Z. 84	— 0·44 -	— 0·03		— 0·47 -	
				1600	875	N.Z. 82	— 0·46 -	— 0·04		— 0·50 -	
				1700	930	N.Z. 84	— 0·57 -	— 0·03		— 0·60 -	

[1] The thermometer Negretti and Zambra No. 75684 was attached to the sounding-line 100 metres above the No. 75682, which was fixed close above the lead.

Distinguishing Number of the Temp.-Series.	Date and Hour. 1894.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
18	Aug. 15	81° 6·6′	127° 49′	0·5° C. SSW 2 Cum.str. 10	1800	984	N.Z. 82	— 0·60 -	— 0·04		— 0·64 -		
					1900	1039	N.Z. 84	— 0·64 -	— 0·03		— 0·67 -		
	Aug. 16	81° 6′	128° 0′	0·2° C. WSW 4 Strat. 10	2100	1148	N.Z. 84	— 0·68 -	— 0·03		— 0·71 -		
					2600	1422	N.Z. 82	— 0·74 -	— 0·04		— 0·78 -		
					2900	1586	N.Z. 84	— 0·76 -	— 0·03		— 0·79 -		
					3000	1640	N.Z. 82	— 0·73 -	— 0·04		— 0·77 -		
	Aug. 17	81° 6′	128° 0′	1·0° C. W 1·7 Cum.str. 10	3400	1859	N.Z. 82	— 0·69 -	— 0·04		— 0·73 -		
					3700	2023	N.Z. 84	— 0·65 -	— 0·03		— 0·68 -		
					3800	2078	N.Z. 82	— 0·64 -	— 0·04		— 0·68 -		
19	Oct. 22	82° 1′	114° 40′	— 34·0° C.	0	0	Sbg. 114	— 0·2 -	+ 0·04	0·0	— 0·16 -		
	Oct. 18	81° 48′	115° 30′	— 30·0° C.	5	2·73	Grave	— 1·46 -	— 0·21	0·0	— 1·67 -		
	Oct. 17	81° 43·5′	115° 40′	— 19·0° C. ESE 6 Cir.str. 10	50	28	-	— 1·64 -	— 0·21	0·0	— 1·85 -		At this time it was difficult to take observations with Pettersson's water-bottle, owing to the low temperature of the air, and the rather disagreeable wind, by which the water-bottle was cooled when it came up. See what is said about these observations on pp. 25, 26. It was necessary to heat the water-bottle in warm water before it was sent down to the desired depth, where it was allowed 10 or 15 minutes to assume the temperature of the water-stratum, before it was closed and hauled up. The temperature-readings taken in this manner from depths below 300 m. are, however, lower than those taken with the reversing thermometer, and do not seem to be trustworthy, for which reason they are here placed in brackets. They are only used for the depths of
					100	55	-	— 0·08 - [1]					
					150	82	- N.Z. 82	— 0·33 - — 0·42 -	— 0·22 — 0·10	0·0	— 0·55 - — 0·52 -	— 0·54 -	
					200	109	Grave	0·75 -	— 0·22	0·0	0·53 -		
					250	137	-	0·84 -	— 0·23	+ 0·04	0·65 -		
					300	164	- N.Z. 82	0·87 - 0·80 -	— 0·23 — 0·10	+ 0·06	0·70 - 0·70 -	0·70 -	
	Oct. 18	81° 48′	115° 30′	— 25·0° C. SE 2 Cir.cum. 5	350	191	Grave N.Z. 82	0·68 - 0·76 -	— 0·22 — 0·10	+ 0·07	(0·53 -) 0·66 -	0·66 -	
					400	219	Grave N.Z. 82	0·61 - 0·78 -	— 0·22 — 0·10	+ 0·07	(0·46 -) 0·68 -	0·68 -	

					450	246	N.Z. 82	0·74 -	—0·10		0·64 -	0·64 -
							Grave	0·73 -	—0·22	+ 0·07	(0·58 -)	
					500	273	N.Z. 82	0·62 -	—0·10		0·52 -	0·52 -
							Grave	0·62 -	—0·22	+ 0·07	(0·47 -)	
					600	328	N.Z. 82	Mercury not broken off.				
							Grave	0·39 -	—0·22	+ 0·05	0·22 -	0·30 -?
					700	383	N.Z. 82	Mercury not broken off.				
							Grave	0·18 -	—0·22	+ 0·04	0·00 -	0·10 -?
	Oct. 19	81° 55′	115° 8′	—17·0° C. SE b E 11 Strat. 10	800	437	N.Z. 82	0·09 -	—0·10		—0·01 -	—0·01 -
							Grave	0·01 -	—0·22	+ 0·03	(—0·18 -)	
					1000	547	N.Z. 82	—0·22 -	—0·10		—0·32 -	—0·32 -
							Grave	—0·22 -	—0·22	0·00	(—0·44 -)	
	Oct. 20	82° 0′	114° 51′	—20·0° C. ESE 8 Cum.str. 10	1500	820	N.Z. 84	—0·58 -	—0·10		—0·68 -	—0·68 -
							Grave	0·00 -	—0·22	—0·16	(—0·38 -)	
					2000	1094	N.Z. 84	—0·82 -	—0·10		—0·92 -	—0·92 -
	Oct. 27	82° 4′	114° 35′	—33° C. E 3 Clear	2500	1367	N.Z. 82	—1·14 -	—0·10		—1·24 -	—1·24 -
	Oct. 29	82° 11·2′	113° 13′		3000	1640	-	—0·80 -	—0·10		—0·90 -	—0·90 -
20	Nov. 3 1 p. m.	82° 6′	111° 30′	—34° C. E 4·5 Clear.	0	0	Sbg. 114	—0·27 -	+ 0·03	0·0	—0·24 -	
					0·5	0·27	Grave	—0·13 -	—0·22	0·0	—0·35 -	
					1	0·55	Sbg. 114	—0·38 -	+ 0·03	0·0	—0·35 -	
					2	1·09	Grave	—1·50 -	—0·21	0·0	—1·71 -	1·68 -
					2	1.09	Sbg. 114	—1·68 -	+ 0·03	0·0	—1·65 -	
					3	1·64	-	—1·70 -	+ 0·03	0·0	—1·67 -	1·67 -
					10	5	Grave	—1·50 -	—0·21	0·0	—1·71 -	

600 m. and 700 m., where the reversing thermometer did not register, but there is added a probable correction of 0·08° C., and 0·10° C., to the temperature.
Taken with glass bottle.
Propeller of water-bottle on water-surface.
With glass bottle
With Pettersson's water-bottle.
With glass bottle.
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[1] In the journal —0·08° C. is recorded for this depth, but there is evidently some error.

Distinguishing Number of the Temp.-Series.	Date and Hour. 1894.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc	Correct. Temp. *in situ.*	Mean Value.	Remarks.
20	Nov. 3 1 p. m.	82° 6′	111° 30′	— 34° C. E 4·5 Clear.	25	14	Grave	— 1·56° C.	— 0·21	0·0	— 1·77° C.		The taking of this series of temperatures was connected with the same difficulties as those of the series No. 19 (see remark on p. 124), and the temperatures were taken with the water-bottle in the same manner, and are not considered trustworthy below 200 m., for which reason they are placed in brackets.
					50	28	-	— 1·64 -	— 0·21	0·0	— 1·85 -		
	Nov. 2	82° 6′	111° 30′	— 20° C. E b N 4 Cum.str. 10	75	41	-	— 1·64 -	— 0·21	0·0	— 1·85 -		
					100	55	-	— 1·52 -	— 0·21	0·0	— 1·73 -		
					125	68	-	— 0·93 -	— 0·22	+ 0·01	— 1·14 -	— 1·13° C.	
							N.Z. 82	— 1·01 - [1]	— 0·12		— 1·13 -		
					150	82	Grave	— 0·30 -	— 0·22	+ 0·01	— 0·51 -	— 0·52 -	
							N.Z. 82	— 0·40 -	— 0·12		— 0·52 -		
					200	109	Grave	0·64 -	— 0·22	+ 0·02	(0·44 -)		
							N.Z. 82	0·68 -	— 0·12		0·56 -	0·56 -	
					250	137	-	0·73 -	— 0·12		0·61 -	0·61 -	
					310	170	Grave	0·78 -	— 0·23	+ 0·06	(0·61 -)		
							N.Z. 82	0·88 -	— 0·12		0·76 -	0·76 -	
					350	191	Grave	0·68 -	— 0·22	+ 0·07	(0·53 -)		
							N.Z. 82	0·70 -	— 0·12		0·58 -	0·58 -	
					400	219	Grave	0·80 -	— 0·23	+ 0·07	(0·64 -)		
							N.Z. 82	0·70 -	— 0·12		0·58 -	0·58 -	
	Nov. 3	82° 6′	111° 30′	— 34° C. E b S 5 Clear.	600	328	N.Z. 82	Mercury not broken off.					
							Grave	0·23 -	— 0·22	+ 0·05	(0·06 -)		
					700	383	N.Z. 82	Mercury not broken off.					
							Grave	— 0·10 -	+ 0·22	+ 0·04	(— 0·28 -)		
					1000	547	N.Z. 82	— 0·22 -	— 0·12		— 0·34 -	— 0·34 -	
21	1895 April 6	84° 18′	96° 40′	— 32° C. E 0 Clear.	0	0	Müll. 6	— 1·85 -	— 0·06	0·0	— 1·91 -		Only these two readings were taken, as during the hauling up from the next depth, the sounding-line broke, and Pettersson's water-bottle was lost.
					5	2·73	-	— 1·80 -	— 0·06	0·0	— 1·86 -		

22	May 13	84° 39′	88° 30′	— 10·4° C. E b N 3·6 Str. 10	0 0	0 0	- Sbg. 114	— 1·64 - — 1·72 -	— 0·06 + 0·02	0·0 0·0	— 1·70 - — 1·70 -	— 1·72 -
	May 25	84° 40′	82° 15′	— 7·9° C. NE 3 Fog 10	0	0	Müll. 6	— 1·67 -	— 0·06	0·0	— 1·73 -	
	May 20			— 10·2° C. E b S 0·0 Cir.str. 10	0 1 2 3 4	0 0·35 1·10 1·64 2·19	Sbg. 114 - - - -	— 1·75 - — 1·80 - — 1·75 - — 1 75 - — 1·75 -	+ 0·02 + 0·02 + 0·02 + 0·02 + 0·02	0·0 0·0 0·0 0·0 0·0	— 1·73 - — 1·78 - — 1·73 - — 1·73 - — 1·73 -	
	May 13	84° 39′	88° 30′	— 10·4° C. E b N 3·6 Str. 10	10 10 20 30 40 50 60 80 100 120 140 160 180 200	5·5 5·5 11 16 22 28 33 44 55 66 77 87 98 109	N.Z. 82 - - - - - - - - - - - - -	— 1·70 - — 1·68 - — 1·67 - — 1·70 - — 1·80 - — 1·80 - — 1·79 - — 1·77 - — 1·78 - — 1·40 - — 0·75 - — 0·02 - 0·40 - 0·84 -	— 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13 — 0·13		— 1·83 - — 1·81 - — 1·80 - — 1·83 - — 1·93 - — 1·93 - — 1·92 - — 1·90 - — 1·91 - — 1·53 - — 0·88 - — 0·15 - 0·27 - 0·71 -	— 1·82 -
	May 14			— 11·2° C. NW b N 3·6 Str. 10	225 250	123 137	- -	0·85 - 1·15 -	— 0·13 — 0·13		0·72 - 1·02 -	
	May 15	84° 38	88° 0′	— 14·3° C. N b E 3 Str. 10	275 300 325 325 350	150 164 178 178 191	- - - - -	1·15 - 1·10 - 1·19 - 1·19 - 1·14 -	— 0·13 — 0·13 — 0·13 — 0·13 — 0·13		1·02 - 0·97 - 1·06 - 1·06 - 1·01 -	1·06 -

The hauling up took 2 m. 40 sec.	
Taken May 14th.	

[1] In the Journal the record was 0·11° C., but this is probably a mistake for 1·01° C.

Distinguishing Number of the Temp.-Series.	Date and Hour. 1895.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
	May 15	84° 38′	88° 0′	— 14·3° C.	400	219	N.Z. 82	0·95 -	— 0·13		0·82 -		
	May 16	84° 37′	87° 45′	— 14·6° C.	450	246	-	1·85 -	— 0·13		(1·72 -)[1]		[1] This temperature seems improbable. The thermometer No. 75682 suddenly began to register irregularly on this day. First from 550 m. the mercury column had not broken off, then from 450 m. it registered —5·50 C., and the next time 1·85. Then from 500 m it registered 0·70° C., from 550 —5·60 C., from 600 m. 0·65° C. As the mercury column broke off now above, now below the contraction of stem, No. 75684 was used instead of this thermometer.
				NE b N 1·8	450	246	N.Z. 84	0·80 -	— 0·13		0·67 -		
				Str. 10	500	273	N.Z. 82	0·70 -	— 0·13		0·57 -		
					550	301	N.Z. 84	0·60 -	— 0·13		0·47 -		
					600	328	N.Z. 82	0·65 -	— 0·13		0·52 -		
					650	355	N.Z. 84	0·45 -	— 0·13		0·32 -		
					700	383	-	0·35 -	— 0·13		0·22 -		
					746	408	-	0·20 -	— 0·13		0·07 -		
	May 22	84° 40′	83° 51′	— 6·0° C.	800	437	-	0·15 -	— 0·13		0·02 -		
				SE 7	850	465	-	0·05 -	— 0·13		— 0·08 -		
				Str. 10									
	May 24	84° 41·4′	82° 24′	— 10·0° C.	900	492	-	0·00 -	— 0·13		— 0·13 -		
				NNE 6	1000	547	-	— 0·15 -	— 0·13		— 0·28 -		
				Cum.str. 10									
	May 25	84° 40′	82° 15′	— 7·9° C.	1100	601	-	— 0·2 -	— 0·13		— 0·33 -		
				NE 3	1200	656	-	— 0·32 -	— 0·13		— 0·45 -		
				Fog 10									
23[1]	July 20	84° 39′	73° 30′	0·3° C.	0	0	Sbg. 118	0·46 -	+0·03		0·49 -		In lane with glass bottle.
				NNE 4									
				Fog									
	July 27	84° 29′	73° 30′	— 1·0° C.	0	0	- ?	— 0·45 -	+0·03?		— 0·42 -	0·08 -	The reasons why the temperature is so low on the surface, and at 0·5 m., on this day, are evidently the low temperature of the air, the snow, and the strong wind stirring the water-strata.
				SW b W 9									
				Snow									
	July 31	84° 28·1′	75° 35′	0·0° C.	0	0	Müll. 6	0·22 -	—0·06		0·16 -		In water-hole with Pettersson's water-bottle.
				WSW 7									
				Cust. 10									
	July 20			0·3° C.	0·5	0·27	Sbg. 118	0·40 -	+0·03		0·43 -	— 0·02 -	In lane.
				Fog									
	July 27			— 1·0° C.	0·5	0·27	- ?	— 0·50 -	- ?		— 0·47 -		—
				Snow									

July 20			0·3° C. Fog	0·75	0·41	-	— 0·40 -	+0·03		— 0·37 -	— 0·37 -		
July 20			0·3° C. Fog	1	0·55	-	— 1·48 -	+0·03		— 1·45 -	— 1·16 -		The strong wind has evidently mixed this stratum with water from the surface on July 27th.
July 27			1·0° C. Snow	1	0·55	- ?	— 0·90 -	- ?		— 0·87 -			
July 27			— 1·0° C. SW b W 9	1·25	0·68	- ?	— 1·68 -	+0·03?		— 1·65 -	— 1·65 -		
			Cu.st. 10	1·5	0·82	- ?	— 1·72 -	+0·03?		— 1·69 -	— 1·69 -		
July 20			0·3° C. NNE 4	2	1·09	-	— 1·72 -	+0·03?		— 1·69 -	— 1·69 -		
			Fog	3	1·64	-	— 1·70 -	+0·03		— 1·67 -	— 1·68 -		
July 27			— 1·0° C.	3	1·64	- ?	— 1·72 -	+0·03?		— 1·69 -			
July 20			0·3° C.	4	2·19	-	— 1·68 -	+0·03		— 1·65 -	— 1·66 -		
July 27			— 1·0° C.	4	2·19	- ?	— 1·70 -	+0·03?		— 1·67 -			
July 31	84° 28·1′	75° 35′		20	11	N.Z. 80	— 1·73 -	— 0·06		— 1·79 -			
				40	22	-	— 1·82 -	— 0·06		— 1·88 -			
				60	33	-	— 1·82 -	— 0·06		— 1·88 -			
				80	44	-	— 1·80 -	-		— 1·86 -			
				100	55	-	— 1·72 -	-		— 1·78 -			
				120	66	-	— 1·53 -	-		— 1·59 -			
				140	77	-	— 1·42 -	-		— 1·48 -			
July 29	84° 32′	74° 17′	— 1·0° C.	160	87	N.Z. 82	— 0·70 -	— 0·10		— 0·80 -	— 0·83 -		
			NE 5			N.Z. 80	— 0·80 -	— 0·06		— 0·86 -			
			Cir.str. 10	180	98	N.Z. 82	0·45 -	— 0·10		0·35 -	0·10 -		
						N.Z. 84	Mercury not broken off.						
						N.Z. 80	— 0·10° C.	— 0·06		— 0·16 -			
				200	109	N.Z. 84	Mercury not broken off.				0·40 -		
						-	0·35° C.	— 0·10		0·25 -			
						N.Z. 80	0·35 -	— 0·06		0·29 -			
						N.Z. 80	0·47 -	— 0·06		0·41 -			
						N.Z. 82	Mercury not broken off.						
						-	0·75° C.	— 0·10		0·65 -			

[1] The thermometers were allowed from 20 to 25 minutes at the greater depths to assume their permanent indications, and also in order to be certain that the sounding-line had been stretched to its full length. They were allowed from 10 to 15 minutes at the lesser depths.

Distinguishing Number of the Temp.-Series.	Date and Hour. 1895.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
23	July 29	84° 32′	74° 17′	— 1·0° C. NE 5 Cir.str. 10	250	137	N.Z. 82	1·00° C.	-		0·90° C.	1·00° C.	
							N.Z. 80	1·15 -	— 0·06		1·09 -		
					300	164	-	1·20 -	-		1·14 -		
							N.Z. 82	Mercury broken off in wrong place.					
					350	191	N.Z. 84	1·25 -	— 0·10		1·15 -	1·15 -	
							N.Z. 80	1·20 -	— 0·06		1·14 -		
					400	219	N.Z. 84	1·05 -	— 0·10		0·95 -	0·95 -	
							N.Z. 80	1·00 -	— 0·06		0·94 -		
					500	273	N.Z. 84	0·79 -	— 0·10		0·69 -	0·70 -	
							N.Z. 80	0·77 -	— 0·06		0·71 -		
					600	328	N.Z. 84	0·62 -	— 0·10		0·52 -	0·53 -	
							N.Z. 80	0·60 -	— 0·06		0·54 -		
	July 30	84° 33·6′	74° 17′	0·9° C. W b S 4 Cu.st. 10	700	383	N.Z. 80	0·50 -	-		0·44 -		Was obliged to stop after this one temperature, as the strong wind causes such motion in the ice that no place is safe (Blessing's note in journal).
							N.Z. 84	Mercury not broken off.					
	July 31	84° 28·1′	75° 56′	0·0° C. WSW 7 Cu.st. 10	800	437	N.Z. 80	0·17 -	— 0·06		0·11 -		
					800[1]	437	-	0·15 -	-		0·09 -		[1] The men who hauled up were uncertain whether this depth was 830 m. or 800 m. (Blessing's note in journal).
					850	465	-	0·05 -	-		— 0·01 -		
					900	492	-	0·00 -	-		— 0·06 -		
					950	519	-	— 0·07 -	-		— 0·13 -		
	July 25			0·5° C. SW b S 7 Str. 10	1000	547	N.Z. 84	— 0·25 -	— 0·10		— 0·35 -		
					1100	601	-	— 0·36 -	-		— 0·46 -		
					1200	656	-	— 0·40 -	-		— 0·50 -		
					1300	711	-	— 0·50 -	-		— 0·60 -		
	July 26			— 0·2° C. SW b S 8 Str. 10	1400	766	-	— 0·64 -	-		— 0·74 -		
					1500	820	-	— 0·67 -	-		— 0·77 -		
					1600	875	-	— 0·55 -	-		— 0·65 -		
					1700	930	-	— 0·7 -	-		— 0·80 -		

24	Dec. 9	85° 25′	53° 47′	— 38·0° C. ESE 3	0	0	Sbg. 118	— 1·85 -	0·00		— 1·85 -		
	Nov. 12	85° 52′	66° 11′	— 24·0° C. SW b S 2	1	0·55	-	— 1·80 -	-		— 1·80 -		
					5	2·73	-	— 1·80 -	-		— 1·80 -	— 1.83 -	
	Dec. 9			— 38·0° C.	5	2·73	-	— 1·85 -	-		— 1·85 -		
	Nov. 30	85° 28·6′	58° 44′	— 37·0° C.	150	82	N.Z. 84	— 1·25 -	— 0·16		— 1.41 -		On account of the low temperature, the steel-wire sounding-line became so stiff and brittle that, after a conference with the captain, I had to be satisfied with determining the upper and lower limits of the warm current, and then taking a few temperatures and water-samples from the intermediate strata of the latter, and a single one from 1900 m. where there was a splice, which I did not trust. (Blessing's note in journal).
					200	109	N.Z. 80	0·15 -	— 0·06		0·09 -		
					250	137	-	0·60 -	-		0·54 -		
	Dec. 2	85° 28·4′	57° 45′	— 40·0° C. SE 2 Clear 0	450	246	-	0·75 -	-		0·69 -		
					550	301	-	0·57 -	-		0·51 -		
					800	437	-	0·18 -	-		0·12 -		
					850	465	-	0·03 -	-		— 0·03 -		
					900	491	-	0·00 -	-		— 0·06 -		
					1900	1039	-	— 0·65 -	-		— 0·71 -		
	1896												
25	Jan. 19	84° 50′	29° 0′	— 21·0° C. SE b S 7	0	0	Sbg. 118	— 1·90 -	0·0		— 1·90 -	— 1·91 -	
	Feb. 14	84° 19′	22° 52′	— 35·0° C. SSE 7	0	0	-	— 1·92 -	-		— 1·92 -		
	Jan. 19			— 21·0° C.	5	3	-	— 1·92 -	-		— 1·92 -	— 1·92 -	
	Feb. 14			— 35·0° C.	5	3	-	— 1·92 -	-		— 1·92 -		
	Feb. 1	84° 50′	29° 0′	— 24·0° C. SE b S 8	175	96	N.Z. 80	— 0·40 -	— 0·06		— 0·46 -		During the work, the sounding-line was carried about 10° out of the perpendicular towards SE by the current.
					200	109	-	0·18 -	-		0·12 -		
					500	273	-	0·85 -	-		0·79 -		
					550	301	-	0·65 -	-		0·59 -		
					875	478	-	0·03 -	-		— 0·03 -		
					900	492	-	0·00 -	-		— 0·06 -		
					975	533	-	— 0·10 -	-		— 0·16 -		
26	April 22	84° 6′	12° 26′	— 15·3° C. E 8	0	0	Sbg. 118	— 1·92 -	0·0		— 1·92 -		
					5	3	-	— 1·92 -	-		— 1·92 -		

Distinguishing Number of the Temp.-Series.	Date and Hour. 1896.	North Lat.	East Long.	Atmosphere.	Depth in Metres.	Depth in Engl. Fath.	Designation of Thermometer.	Deep-Sea Temperature. Reading.	Instr. Error.	Corr. for pressure, etc.	Correct. Temp. *in situ.*	Mean Value.	Remarks.
26	April 15			— 30·0° C. NE b N 5	175	96	N.Z. 80	— 0·23° C.	— 0·06		— 0·29° C.		
					185	101	-	— 0·15 -	-		— 0·21 -		
					200	109	-	0·40 -	-		0·34 -		
	April 16	84° 5′	15° 0′	— 27·0° C. NE b N 5	200	109	N.Z. 80	0·06 -	-		0·00 -		
					225	123	-	0·82 -	-		0·76 -		
					225	123	-	0·80 -	-		0·74 -		
					500	273	-	0·95 -	-		0·89 -		
					600	328	-	0·67 -	-		0·61 -		
					875	478	-	0·15 -	-		0·09 -		
	April 15	84° 7′	16° 0′	— 30·0° C. NE b N 5	900	492	-	0·05 -	-		— 0·01 -		
	April 16	84° 5′	15° 0′	— 27·0° C. NE b N 5	925	506	-	0·00 -	-		— 0·06 -		
					950	520	-	— 0·02 -	-		— 0·08 -		
					1000	547	-	— 0·17 -	-		— 0·23 -		
	April 15	84° 7′	16° 0′	— 30·0° C. NE b N 5	3000	1640	-	— 0·82 -	-		— 0·88 -		

PART 2.

THE SPECIFIC GRAVITY AND THE SALINITY OF THE WATER IN THE NORTH POLAR BASIN.

I.

INTRODUCTION.

One of the demands of modern Oceanography should be that the specific gravity and the salinity of the water from all depths of the Ocean be determined with the highest possible degree of accuracy.

The time is now past when it was sufficient to decide whether the water found was of Atlantic or Polar origin etc. We should constantly keep in view that our observations ought to retain their value for at least a hundred years, and that in order to enable future science to acquire a fairly accurate knowledge of the circulation of the Ocean and its temporary and secular changes it is necessary that we attain such a degree of accuracy in our determinations as to be able to demonstrate with certainty at least differences of as little as one unit in the fifth decimal place of the specific gravity of the seawater.

Oceanographic research can hardly pretend to have hitherto, as a rule, approached anywhere near such a degree of accuracy; and it is to be feared that much of the Oceanic work of to-day is to some extent wasted, as it has to be repeated with better methods, the determinations not being so accurate as to possess permanent value. This is partly due to imperfect water-bottles, which have not given trustworthy water-samples, and partly also to the unsatisfactory methods by which the specific gravity and salinity have generally been determined.

I regret much that although I had my attention fully directed towards this point, I have not succeeded in attaining the degree of accuracy which I

much desired, in the determination of the specific gravity of the sea-water in the North Polar Basin. This is not due to any fault in the water-bottle, but to the method of determining the specific gravity, which can certainly be much improved.

For a really accurate and reliable determination of the salinity and specific gravity of the sea-water from the various depths, the following points are very important.

(1). The water-bottle used must be perfect, which means (*a*) that it should be an impossibility for it to close before this is desired, but also when desired, that it should be equally impossible for it not to close; and (*b*) when shut, it must fit perfectly tight, in order to retain the water-sample enclosed absolutely unchanged.

(2). The water-sample should be poured into clean bottles, without any possibility of its being mixed with other water, *e. g.* drops of water adhering to the outside of the water-bottle or to the inside of the glass bottle. The stopper of the glass bottle should be perfectly tight; and the glass of the bottle should not dissolve easily in water. If it does so, this might be remedied by boiling it in distilled water, or treating it with superheated steam.

(3). The specific gravity, or the salinity (or halogen) of the water-sample should be determined as soon as possible with the highest possible degree of accuracy, that is to say, the specific gravity should be determined at least with an accuracy of $\pm$ 0·00001 and the salinity with an accuracy of $\pm$ 0·02 ‰.

I believe our investigations on board the Fram have been very successful as regards the first two points; our weak point will be the third.

(1). *The water-bottles* used for taking water-samples will be specially mentioned tater. I feel certain that the water-samples taken were as a rule very reliable, especially those taken with the Pettersson insulated water-bottle.

It has generally been considered a satisfactory test, to let a water-bottle hang filled for some time, and to see whether any water ran out, if not the bottle was declared to be tight. This, in my opinion, is no satisfactory test, for even if a water-bottle seemed tight while hanging thus, it is quite possible that it will allow a slow diffusion between the water inside and the water outside the bottle, while it is being hauled more or less rapidly up through the water-strata.

A good test of the tightness of a water-bottle, in my opinion, is to fill it with distilled water, immerse it in the sea, and there move it about or haul it up and down, say for an hour or two. It must of course not be lowered so deep that the water contained is appreciably compressed by the overlying water. When the water-bottle is again taken up, it should not be possible to demonstrate the presence of salt in the sample of distilled water by adding drops of a solution of nitrate of silver. I have made the experiment, and have found that it is most difficult to get a water-bottle so water-tight that it will stand this test quite perfectly, even if the bottle while hanging, filled, in the air for hours did not give off a single drop of water; and I feel convinced that in many cases, especially in previous expeditions, the water-bottles have been far from fulfilling these conditions. This circumstance certainly explains, to a considerable extent, the apparently discrepant results of various expeditions which have made investigations in the same parts of the Ocean; and it greatly reduces the value of comparisons between the results of the various expeditions, such comparisons, in many cases, leading to more or less erroneous conclusions.

(2). Before the water-samples were taken, the water-bottle was as a rule wiped carefully dry outside near the stop-cock, and in order to get rid of any drop of water that might be hanging in the mouth of the stop-cock, this was opened, and a little water allowed to run out, before the water-sample was taken in the glass bottle.

Special care has to be taken in this respect among the ice in the Polar Sea, as during the summer and autumn its surface is covered with nearly pure fresh water, arising from the melting of the snow and ice. One or two drops of this surface-water, in a water-sample of 400 cubic centimetres, is sufficient to reduce its specific gravity by 0·00001.

Before the samples were bottled, the glass bottles were always well rinsed with water of the same kind, generally from the same water-sample, and taken from the outer chambers of the water-bottle.

(3). When taken, the water-samples were brought into my laboratory, where they remained until they were examined, which was sometimes done the same day, but as a rule a day or two later.

PETTERSSON'S WATER-BOTTLE.

On page 3 *et seq.* I have discussed the insulating properties of this excellent water-bottle. I shall here mention my experiences with it as an instrument for taking water-samples. The only part of the instrument that caused me any trouble was the arrangement of the propeller and the hooks by which the upper lid hangs when the water-bottle is open.[1] The hooks were soon worn by use, and would not catch well, so that they were sometimes released before it was desired. They had then to be filed square again, but this had to be done very carefully, so that both hooks would catch equally well. Again, when it was cold, ice would freeze on the hooks, and there was no little difficulty in making them catch so well that they were not too easily released.

For future work, I would therefore strongly recommend an alteration in this arrangement. On a new water-bottle, I have made a hook on which the upper lid hangs by a shackle, and which is released by the propeller. The accompanying figure will explain this arrangement. The advantage is that the shackle (*h*) of the lid (*l*) cannot possibly be released before the propeller (*p*) has passed so far upwards through the water, that the lower extremity (*t*) of its axle (*a*) has risen above the edge (*e*) of the hole in the upper part of the hook. But at that very moment, the shackle, *h*, with the lid, must be set free, as it hangs a little eccentrically on the hook, and will force this to one side, as indicated by the dotted outline, as soon as the upper end is released. By the stopper, *s*, which can be raised or lowered by the screw, *b*, the distance that the propeller has to move through the water before it releases the hook can easily be regulated. By a strip of india-rubber (*i*), the shackle (*h*) is kept in

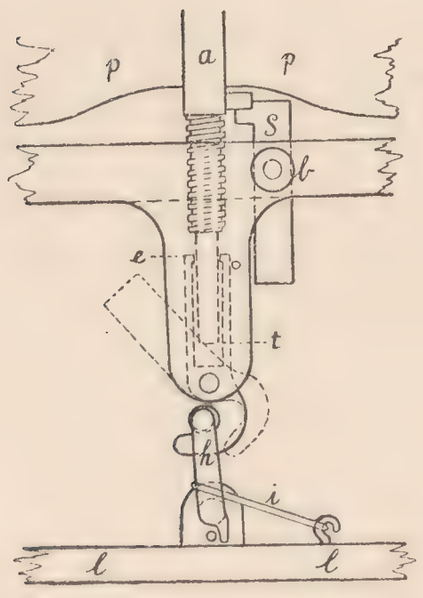

Fig. 1.

[1] See Pettersson's description of this arrangement, Scott. Geogr. Mag. June, 1894, p. 284, and Pl. I, fig. 3.

position and prevented from slipping off the hook, as long as the water-bottle is to remain open. I have found this arrangement very reliable, and it works with great accuracy. For lesser depths, where the salinity and temperature of the water-strata differ much, I prefer the use of a messenger, as I can then control the depth more accurately. The same apparatus may be used, the propeller being replaced by a very simple arrangement for messenger. In greater depths, I think the messenger requires too long a time, and I there prefer the propeller for ordinary purposes.

The hooks by which the cylindrical body of the instrument is kept in position on the two rods, when the instrument is open, also often gave some trouble, as they would not work when ice was forming on the instrument. It would be a simpler and more reliable arrangement if the cylindrical body were suspended by hooks or rods at a certain distance under the upper lid, but connected with it.

In order to test the tightness of Pettersson's water-bottle, I often let it hang filled for some time, but never discovered the slightest indication of leakage. I opened the hole at the top, for the insertion of the thermometer, and let it hang with this open; but even then only a few drops of water accumulated at its lower end. On some occasions I took samples of water both from the outer chambers of the bottle and from its central tube, but could not, as a rule, with certainty find any difference whatever between them. As instances, I may mention the following determinations by hydrometer, made on the 23rd and 25th June, 1894.

Depth.		$S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$
120 m.	Sample from central tube. By 6 determinations	1·02624
—	— — outer chambers. By 5 determinations	1·02621
140 m.	Sample from central tube. By 2 determinations	1·026325
—	Samples from central and outer tubes mixed. By 3 determinations	1·026327
160 m.	Sample from central tube. By 2 determinations	1·02642
—	Samples mixed from central and outer tubes. By 3 determinations	1·02640
180 m.	Sample from central tube. By 3 determinations	1·02643
—	Samples mixed. By 4 —	1·02648
200 m.	Sample from central tube. By 5 determinations	1·02662
—	Samples mixed. By 4 —	1·026605
225 m.	Sample from central tube. By 3 determinations	1·02661
—	Samples mixed. By 5 —	1·026614
250 m.	Sample from central tube. By 2 determinations	1·02678
—	Samples mixed. By 3 —	1·02679

It will be seen that the cases in which the samples from the central tube have a higher specific gravity than those from the outer water-chambers, or than water of both kinds of samples mixed, are very nearly equal in number to those in which the reverse is the case, and the differences are in most cases so slight, that they are well within the limits of the errors of observation.

We may therefore feel assured that the Pettersson water-bottle used during our expedition has practically been perfectly water-tight, and the water-samples taken by it have been highly trustworthy.

If, however, the bottle be hauled up at a very irregular rate of speed, *e. g.* from a ship in a heavy sea, it may have a tendency to leak; for sometimes when hauled up very rapidly, the pressure of the lid and bottom against the cylinders is increased, the india-rubber plates are compressed, and the volume of the bottle is consequently diminished, and some water is pressed out wherever it can find an egress. At other times, when the movement nearly ceases, the pressure of the lid and bottom against the cylinders is greatly reduced, the india-rubber plates expand, and the volume of the bottle is again increased; and consequently some water from outside must find its way into the bottle to make up for this expansion. In this manner, the accuracy of the water-samples taken may be somewhat vitiated, although the quantity of water pressed out of, and forced into, the water-bottle is naturally very trifling. In order entirely to exclude the possibility of this slight forcing of water into and out of the bottle, I think it is an advantage to give the water-bottle two automatic locks, one on each side, which, as soon as the bottle is closed, are put in action, and press the lid and bottom together upon the cylinders with a constant and considerably increased pressure. In another paper I shall describe some water-bottles of this construction.

EKMAN'S INSULATED WATER-BOTTLE.

Prof. Otto Pettersson also had the kindness to have an insulated water-bottle of Ekman's pattern[1] made for the expedition, to be used as a reserve

[1] This instrument is described in 'Den Svenska hydrografiska Expeditionen år 1877', af F. L. Ekman. Kgl. Svenska Vet.-Akad. Handl., vol. XXV, No. 1, Part I, p. 17.

instrument. This water-bottle, however, was used only a few times during the expedition, as I found it to have several serious defects. A wire sounding-line of bronze or steel cannot be used with it, as it sinks too slowly. Again, it is heavy to haul up, and if the line does not run out quite freely and without any stop, there can never be a certainty that the bottle has not closed before it reaches the desired depth. The greatest drawback was, however, that it did not close tightly. On April 27th, 1894, I took two samples with this bottle from 1400 and 1600 metres, but found that their specific gravity was considerably lower than that of samples taken with Pettersson's water-bottle from the same depths. The differences between the specific gravities at $\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$ were:

Depth.	*Sample taken with Ekman's water-bottle.*	*Sample taken with Pettersson's water-bottle.*
1400 m.	1·02503	1·02693
1600 m.	1·02624	1·02683

This difference seemed to be chiefly owing to leakage in Ekman's water-bottle. This was the more evident as the lower water-layers in the bottle were heavier than the upper ones, as may be seen from the following determinations of the specific gravity.

Depth.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$ *of sample from the lower strata of the water-bottle.*	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$ *of sample from the upper strata of the water-bottle.*
1400 m.	1·02523	1·02483
1600 m.	1·02648	1·02602

It will be seen that in both cases there is a difference in the specific gravity of about 0·00040 or 0·00046 between the lower and upper strata of water in the bottle, *i. e.* between the sample taken first and that taken last. This can of course only be explained by the fact of an active communication between the water inside and outside the bottle during the hauling up.

After this discouraging experience with Ekman's water-bottle, this instrument was not used again during the whole expedition.

BLESSING'S WATER-BOTTLE.

All water-samples were taken with Pettersson's water-bottle until April 6th, 1895, when it was lost by an accident. The sounding-line of steel-wire broke, probably at some kink, while the bottle was being hauled up. Dr. Blessing now designed a new water-bottle, which was made by Mr. Amundsen, the first engineer of the Fram, and which proved very satisfactory for taking water-samples. It consisted merely of a single brass tube, as there was not sufficient material on board to make an insulated water-bottle with concentric water-jackets like Pettersson's. From this time the water-temperatures were therefore only taken with Negretti and Zambra's deep-sea thermometers, while the water-samples were taken with this bottle. In construction it greatly resembles Pettersson's bottle. The chief parts are the bottom, the tube, and the upper lid. To the bottom and the lid there are fixed two large plugs of india-rubber, fitting into the ends of the brass tube. On the top of the lid there is a heavy weight of lead, which, when the lid is released, will press the latter, with the plug, down against the upper edge of the tube. This drops down and is pressed against the bottom. Thus the plugs are forced by the weight into the tube at both ends, and close it very effectually. The construction of the propeller for releasing the hooks of the upper lid when the instrument is hauled upwards, is the same as in Pettersson's water-bottle. When the water-bottle is open, the tube is kept in place by some small springs, which were not, however, able to hold the tube when the weight of the lid rested upon it. The closing of the bottle was so perfect, that when the stop-cock at the lower end of the cylinder was opened, not a drop of water came out until the upper lid was lifted.

The dimensions of this water-bottle were as follows:

The length of the whole apparatus was	62 cm.
The distance between the vertical rods of the frame	8 -
The length of the tube	24 -
The interior diameter of the tube.	5·5 -
The distance that the upper lid had to fall after being released	14 -

The whole apparatus hangs on a swivel in order to prevent the cord from being unduly twisted by the propeller on its passage down through the water. The volume of the water-sample obtained was about 560 c. cm.

This water-bottle has evidently, as a rule, worked very well, a fact which is also apparent when Blessing's determinations of the specific gravity of the water-samples are compared with mine from the same depths. In November and December, 1895, it seems probable, however, that the water-samples taken are not to be relied upon, the water-bottle in several soundings not having worked properly. I should think that it has been closed too soon on its way down through the water.

THE HYDROMETERS.

The specific gravity ($S\frac{t}{17{\cdot}5^\circ\,\mathrm{C.}}$) of the water-samples taken during the expedition was, with few exceptions, determined by the ordinary floating hydrometers of constant weight, and has been reduced to the specific gravity of the water-sample at 17·5° C. compared with distilled water at 17·5° C. ($S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$)

For these determinations the expedition had one set of two glass hydrometers made by C. Åderman of Stockholm, and another set of five glass hydrometers made by Dr. Küchler of Ilmenau, and originally delivered to the Norwegian North Atlantic Expedition of 1876—1878.

The observations were made in the following manner. Before the determination of their specific gravity, the water-samples were generally kept at least one day in my laboratory on board the ship, so that they had nearly assumed the temperature of the room, and had given off most of the superfluous air that they contained. The hydrometers were kept in the same place, and would have nearly the same temperature. The temperature of the room could not, however, be kept very uniform during the winter, as it would sink very considerably during the night.

After April, 1894, a glass cylinder of about 5 cm. inner diameter, and 30 cm. height, was used for these determinations. This was the only suitable vessel left, after a somewhat larger cylinder, used during the first year, 1893, had been broken; but as a piece was broken out of its upper edge, I had to mend it with a plate of white metal (German silver), which was soldered on to the glass cylinder by aid of a mixture containing india-rubber and asphalt, such as is generally used for insulating electric wires. Thus two thirds of the circumference of the upper part of the cylinder con-

sisted of German silver; the rest was glass, through which the indications of the hydrometer had to be read. This arrangement made the act of reading somewhat inconvenient, and a mirror had generally to be used for throwing light on the scale of the hydrometer; but by comparison with simultaneous determinations of the same water-samples, made in a larger glass cylinder, I ascertained that the mended cylinder had no disturbing influence upon the indications of the instrument, although it might seem probable that this vessel would not be so easy to keep clean, and might therefore have had a liability to give off greasy matter to the surface of the water-sample, thus reducing its surface-tension.

This mended glass cylinder was used for nearly all determinations of the specific gravity of the water-samples during the years 1894 and 1895. It has also been used since, in exactly the same state, for hundreds of observations made in 1897, 1898, and 1899, for the purpose of determining the instrumental errors of the hydrometers.

Before use, the hydrometer was carefully wiped dry with a towel or a piece of wash-leather. When immersed, it was dipped a little below its position of equilibrium, in order to wet the stem a short distance above the water-line.

After the instrument had been allowed time to assume the temperature of the water, and it had been ascertained that no air-bubbles were adhering to it, the indication was read off with a lens underneath the water-surface, care being taken that the eye was exactly level with the latter. The hydrometer was then at once raised a centimetre or two, while a thermometer was immersed with its bulb level with the centre of the body of the floating hydrometer. After the temperature had been read, the thermometer was removed, the hydrometer was moved rapidly up and down several times to stir the water, and was then immersed to its position of equilibrium again. In this manner several independent readings were taken of each water-sample; the instrument was moreover, as a rule, taken once or twice out of the water, to be carefully wiped dry, either the whole instrument or the stem only, and new readings were taken.

As is stated in Memoir X (see pp. 22 and 38 *et seq.*), the immersion and removal of a thermometer generally increases the surface-tension of the water, and this explains why the first reading of a series of observations

with the hydrometer is so often higher than the subsequent ones. Believing at that time the reason to be that an up-and-down swinging motion was imparted to the hydrometer by the insertion of the thermometer, and that its stem was thus unduly weighted with water, I raised the instrument a little during the immersion of the thermometer, as mentioned above.[1]

The above method was found, at the time, to give the most trustworthy determinations.[2] Since the return from the expedition, the errors of the hydrometer most used, have been carefully determined by hundreds of observations made in exactly the same manner. It might therefore be expected that our observations during the expedition would give very accurate determinations of the specific gravity of the water of the North Polar Basin. This is nevertheless not the case to such an extent as might be desired. Owing to changes in the surface-tension of the water-samples during the observations, irregular variations have evidently occurred in our determinations. It is, however, only since my return that I have had the necessary time and opportunity to study the true nature of these variations. The results of my investigations on this subject are described in Memoir X.

Upon the whole, I cannot recommend the use of the ordinary floating glass hydrometer of constant weight or of variable weight (Buchanan's pattern) for future work. It might be useful for preliminary estimates; but for final determinations of the specific gravity of the ocean, I would strongly recommend future expeditions to adopt more accurate methods (cf. Memoir X, pp. 82 et seq.), and I would suggest *hydrometers of total immersion* — which can easily be used on board ship, and give a high degree of accuracy — or *pycnometers*, or *hydrostatic weighing*. The last two methods can well be used on board a ship enclosed in the ice as was the Fram. The *refractometrical method* suggested by Hercules Tornøe[3] may conveniently be used on board ship, and gives very accurate determinations.[4]

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[1] For the correct explanation, see Memoir X, pp. 38, 61, 70, 76, etc.

[2] According to later investigations, I find that it can be much improved. See Memoir X, pp. 80—82.

[3] H. Tornøe, 'On the Determination of the Salinity of Sea Water by its Powers of Refraction'. 'Report on Norwegian Fishery- and Marine-Investigations,' vol. I, No. 6, Christiania, 1900.

[4] Ordinary titration is of course the most convenient method for determination of the amount of chlorine contained in the sea-water, and may give very accurate results, if the determinations are repeatedly (*e. g.* every tenth determination) controlled by 'standard water'; and I have also found it convenient to control them now and then by hydrometers of total immersion.

Åderman No. 2.

The hydrometer of Åderman indicating from 1·0148 to 1·0302 was mostly used for determining the specific gravity of the water-samples during our expedition. This instrument, which I call *Åderman No. 2*, is evidently of the same pattern as those used on the Vega Expedition, and described by Prof. Otto Pettersson.[1]

The length of the instrument is 36·7 cm. The length of the cylindrical glass body with the bulb underneath (filled with shot) is 18·5 cm. and the diameter 34·5 mm. The stem is 18 cm. long, and has a diameter of 4·4 mm. Inside it is fixed a paper scale 126·7 mm. long, which is graduated in divisions of 0·0001, ranging from 1·0148 to 1·0302, the distance between the division-marks being 0·823 mm. With a lens, the indications could thus be read off with tolerable accuracy to the fifth decimal place.

The two hydrometers of Åderman are simply marked 'C. Åderman' without number or date. They had been lying in the Meteorological Office at Christiania, when they came into my possession. I have not been able to find out how they had come there, or when they were made; but as Mr. Åderman died some 15 years ago, they must have been at least eight years old when they came on board the Fram. It is therefore probable that there has been little secular contraction of the glass of the instruments during the expedition, or since that time. Their corrections were not determined before our departure in 1893, but since our return I have tried on several occasions in 1897, 1898, and 1899, to determine the corrections of Åderman No. 2 with a high degree of accuracy, and have not been able to prove any appreciable change in volume.[2] We may therefore assume that the instrument has practically had the same instrumental errors during the expedition as it has at present.

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[1] 'Vega-Expeditionens vetenskapeliga Iagttagelser', vol. II, 1883, pp. 327 *et seq.* These instruments were originally made to give the specific gravity $S\frac{t}{15^\circ\text{C.}}$, and not $S\frac{t}{17{\cdot}5^\circ\text{C.}}$ which would make a difference of about 0·00040. This, combined with the secular contraction of the glass, is evidently the reason why our instrument has such a great correction, if the indications are referred to $S\frac{t}{17{\cdot}5^\circ\text{C.}}$

[2] At minimum indications of the hydrometer, *i. e.* at the maximum surface-tension of the water, its correction was:

When, in September and October, 1897, I first tried to determine the error of Åderman No. 2, in two water-samples with $S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.} = 1{\cdot}027573$ and $1{\cdot}026874$, the average of 31 observations gave me a correction of $+\,0{\cdot}00071$. If, however, the observations made on board the Fram were corrected accordingly, I obtained unexpectedly high specific gravities for the water of the North Polar Basin, the highest $S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$ being about $1{\cdot}02700$, which would correspond to a salinity of about $35{\cdot}51\,‰$. This result appeared *a priori* highly improbable. The probability seemed to be that the instrument had, as a rule, had some lower corrections during the observations made on board. I had to set to work to find this out, and the result was the long and troublesome investigations described in Memoir X.

According to these investigations, the indications of the hydrometers on board the Fram may have been increased in the following manner:

1. The towels or wash-leather used for wiping the hydrometers, thermometers, and glass cylinder, were not generally quite clean, as they could not be washed very often, and thus the surface-tension of the water-samples examined, may as a rule have been somewhat reduced by greasy contamination of the surface during the observations.

2. The water-samples being newly taken and brought into my laboratory, perhaps a day before the observations, would generally be supersaturated with air. Their surfaces might easily have been contaminated by products of organic life, and this contamination might have heen accelerated by rising air-bubbles, bringing impurities from the interior of the water to the surface (see Memoir X, p. 13 *et seq.*).

3. By the manner in which the observations were made on board the Fram, the immersion and removal of the thermometer was prevented from cleaning the water-surface (and thus increasing its tension) to the same extent as was the case with the observations made in September and October, 1897. On board the Fram, the hydrometer, as mentioned on page 144, was generally

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Date.	$S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$ *of the water-sample used.*	*Correction of Aderman No. 2.*
September and October, 1897	1·02757	+ 0·00080
" " "	1·02687	+ 0·00081
October, 1898	1·02687	+ 0·00081
April, 1899	1·02553	+ 0·00081

raised a little while the thermometer was immersed. Thus the contaminated surface-film of the water might to some extent have been lifted on the hydrometer. And even if the latter, after the removal of the thermometer, was generally moved up and down to stir the water, before it was again immersed to its position of equilibrium, the contamination of the water-surface was not in this manner so easily removed as when a thermometer is repeatedly immersed and removed without raising the hydrometer.

We must consequently expect the surface of the water-samples, as a rule, to have been more or less contaminated during the determinations with the hydrometer on board the Fram. The surface-tension has thus had a tendency to be nearer a minimum than a maximum, *i. e.* the indications of the hydrometer have had a tendency to approach their maximum.

Between September, 1897, and April, 1899, 27 series of observations, numbering 915 in all, were made in eight different water-samples with $S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$ between 1·02097 and 1·02757. I find that for indications of about 1·0260 and 1·0270, the error of the hydrometer, which is indicated too low, varies between + 0·00081, at *maximum tension of the water-surface*, and + 0·00040, at *minimum surface-tension*.[1] These corrections must be the possible upper and lower limit of the corrections of the instrument under ordinary circumstances, as they correspond exactly to the possible changes in the surface-tension of sea-water.

But according to what is stated above, we must expect the upper limit of the instrumental error to have been very seldom reached on board the Fram, as the surface of the water-samples was generally more or less contaminated. I have found the probable upper limit of the errors on board to have been about + 0·00070, while the lower limit, of + 0·00040, has of course been the same, as this would be the error of the instrument, even if the water surface were saturated with oil or greasy matter (cf. Memoir X, p. 27).[2]

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[1] The mean value of the errors at minimum indications of the hydrometer, one in each series, is + 0·00078, and at maximum indications, one in each series, + 0·00051.

[2] In this case I have found the minimum surface-tension (α mg/mm.) of sea-water to be 3·76 (see X, p. 63). If, at a maximum surface-tension of 7·67 of the sea-water at 12° C. (see X, p. 63), the hydrometer Åderman No. 2 would sink sufficiently deep to have a correction of + 0·00081 (determined by many observations), its minimum correction at the minimum of surface-tension should be + 0·00040. It is not therefore possible that the correction would go lower than this — even if the water-surface were completely saturated with oil — provided that the stem is perfectly wetted.

For indications of Aderman No. 2 of about 1·02600 and 1·02700, I therefore correct our observations from the expedition in the following manner:

If, in a series of determinations of the same water-sample, there is much difference between the values of the specific gravity found, I correct the highest value with + **0·00040** to find the *lower* possible *limit* of $S\frac{17{\cdot}5^\circ\text{C.}}{17{\cdot}5^\circ\text{C.}}$,[1] and the lowest value with + **0·00070** to find its *upper limit*. The mean of all determinations is corrected with + **0·00055**, being the mean between the upper and lower limit of the error.

I believe that by accepting these corrections, we may, as a rule, ensure against getting too high values of the specific gravity and salinity of the water of the North Polar Basin. This may be inferred from the following. I have made series of observations under circumstances which were as similar as possible to those on board. The water-samples were brought into my room in the winter, when it was very cold outside, were kept for several days, and stood during the night in a room with a very low temperature, like that of the cabin on board. The hydrometer was wiped with towels which had been used for a long time, and were not clean, and the observations were made in precisely the same manner as during the expedition, and in the same mended glass cylinder, which was kept in the same state of cleanliness (cf. Memoir X, p. 31, foot-note). The specific gravities, $S\frac{17{\cdot}5^\circ\text{C.}}{15{\cdot}5^\circ\text{C.}}$, of the water-samples used — kindly determined by Mr. H. Tornøe with the Sprengel pycnometer — were 1·02534, 1·02644, 1·02650, and 1·02553. The mean value of all the indications of the hydrometer was about 1·026. Fifty-one series, of 10 observations each, were made. Taking the minimum and maximum indications of the hydrometer out of each series, I find that the mean value of the 51 *minimum indications* gives a correction of + 0·00068 for Aderman No. 2, while the 51 *maximum indications* give a mean correction of + 0·00053.

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[1] In a few cases where the indications seem to be exceptionally high, I use a minimum correction of + **0·00035**, which is the absolute minimum of correction, obtained only once in all my hundreds of observations made after the return of the expedition. By rubbing the hydrometer all over with greasy fingers, I obtained on one single occasion (see Memoir X, p. 11) a correction as low as + 0·00035. On three or four other occasions, I obtained corrections as low as + 0·00036 and + 0·00038 by rubbing the stem of the hydrometer with a greasy finger, or by immersing pieces of filter-paper in the water, thus contaminating its surface (see Memoir X, pp. 12, 17, 33, 63 *et seq.*). In these cases the stem must have been greasy and thus imperfectly wetted. With these exceptions, the corrections of the observations never sank below + 0·00040, and as a rule not below + 0·00043.

By averaging all the five hundred observations, we find a mean correction of + 0·00061 for the hydrometer. It is seen that the mean correction of + 0·00055 found above, is probably, if anything, somewhat too low.

At indications lower than 1·0260, I have found the instrument to have somewhat greater errors than at the higher indications. According to my numerous series of determinations, the corrections of the observations made with Åderman No. 2 will therefore be:

Corrections of Åderman No. 2

for referring its indications at t° C to $S\frac{t}{17{\cdot}5^\circ\,\mathrm{C.}}$.

Reading of Instrument.	Minimum Correction.	Mean Correction.	Maximum Correction.
1·02800	+ 0·00039	+ 0·00054	+ 0·00069
1·02700	+ 0·00040	+ 0·00055	+ 0·00070
1·02600	+ 0·00040	+ 0·00055	+ 0·00070
1·02500	+ 0·00041	+ 0·00056	+ 0·00071
1·02400	+ 0·00042	+ 0·00057	+ 0·00072
1·02300	+ 0·00042	+ 0·00057	+ 0·00072
1·02200	+ 0·00043	+ 0·00058	+ 0·00073
1·02100	+ 0·00044	+ 0·00059	+ 0·00074
1·02000	+ 0·00044	+ 0·00059	+ 0·00074

The following examples will show how I think these corrections ought to be applied in the various series of observations taken on board the Fram.

Example 1. Water-sample from 450 m. taken June 26th, 1894, examined same day. Thermometer immersed and removed between each reading of the hydrometer.

Temperature of Water-Sample.	Indication of Åderman No. 2.	Indication referred to 17·5°C.	Correction.	$S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$	Salinity in ‰
6·62	1·02796	1·02622	+ 0·00069	1·02691	35·39
6·72	1·02788	1·02625			
6·94	1·02809	1·02639	+ 0·00039	1·02678	35·22
7·02	1·02792	1·02623			
	Mean:	1·02627	+ 0·00054	1·02681	35·26

We see that the lowest indication, 1·02622, corrected with + 0·00069, gives 1·02691 as a maximum value, and the highest indication, 1·02639, corrected with + 0·00039, gives 1·02678 as a minimum value, while the mean of all the indications, 1·02627, corrected with 0·00054, gives 1·02681 as the final result. This corresponds to the salinity of 35·26 ‰.

Example 2. Water-sample from 3000 metres, taken on October 27th, 1894, examined November 12th, 1894.

The temperature of the air was at this time about − 30°C. outside; the temperature of the laboratory sank nearly to zero centigrade during the night; the water-sample has probably contained much air, and its surface-tension might be expected to have been reduced by rising air-bubbles. Great variation in the indications of the hydrometer are therefore probable. The hydrometer was moved up and down to stir the water between each reading; before the seventh reading, it was taken up and wiped dry. The thermometer was hanging in the water continuously during all the observations, and this has tended to increase the indications of the hydrometer, the surface-tension not being diminished by the immersion and removal of the thermometer, as was generally the case.

Temperature of the Water.	Indication of Åderman No. 2.	Indication referred to 17·5°C.	Correction.	$S\frac{17{\cdot}5^\circ\text{C.}}{17{\cdot}5^\circ\text{C.}}$	Salinity ‰
13·9	1·02718	1·02648	+ 0·00035	1·02683	35·28
14·3	1·02688	1·02625			
·3	1·02688	1·02625			
·5	1·02688	1·02629			
·6	1·02678	1·02621			
·6	1·02680	1·02623			
·9	1·02678	1·02626			
15·1	1·02664	1·02616	+ 0·00070	1·02686	35·32
·4	1·02666	1·02624			
·4	1·02671	1·02629			
·7	1·02670	1·02634			
·7	1·02668	1·02632			
	Mean:	1·02628	+ 0·00055	1·02683	35·28

The specific gravity of this water-sample should consequently be 1·02683, corresponding to a salinity of 35·28 ‰, which cannot be too high, for the highest indication of the hydrometer reduced to 17·5°C. is 1·02648, and the lowest 1·02616. If we correct these observations with the absolute minimum (+ 0·00035) and the absolute maximum (+ 0·00081) corrections of the instrument, we find that the specific gravity cannot possibly have been below 1·02683, and not above 1·02697.

The Hydrometer Åderman No. 1.

This instrument, indicating from 0·9990 to 1·0152, was of exactly the same shape and dimensions as Åderman No. 2. In two water-samples with specific gravities, $S\frac{17{\cdot}5^\circ\text{C.}}{17{\cdot}5^\circ\text{C.}}$, of 1·01496 and 1·01372 (according to determinations

with the hydrometer of total immersion) several determinations were made with this instrument, giving it a mean correction of **+ 0·00040**, the hydrometer indicating too low.

Its minimum correction is + 0·00026, and its maximum correction, at maximum of surface-tension, is + 0·00066.

The Hydrometer Küchler No. 4.

Among the set of Küchler hydrometers[1] was one ranging from 1·018 to 1·025 ($S\frac{t}{17{\cdot}5^\circ\,C.}$), which I have called Küchler No. 4, and which was used several times during the expedition. 39 determinations made with this hydrometer, and 48 determinations made simultaneously with Aderman No. 2 and Tornøe's electric apparatus (see later) in the same water-samples, on July 27th, 1893, April 18th and 21st, 1894, June 22nd and 28th, 1894, July 11th, 1894, and October 15th, 1894 (see Table later), give a mean correction for Küchler No. 4 of **— 0·00027.**

The maximum correction under ordinary circumstances is — 0·00012, and the minimum correction — 0·00042.

Outside the case of the instrument, its correction was stated to be — 0·00037, but when or by whom this correction was determined I have not been able to ascertain. The instrument went out again with Capt. Sverdrup on his expedition in the Fram to the north-west coast of Greenland, before I got an opportunity of determining its corrections more accurately.

The Hydrometer Küchler No. 3.

This instrument, ranging from 1·012 to 1·019 ($S\frac{t}{17{\cdot}5^\circ\,C.}$), was used several times for determining the specific gravity of the water from the sea-surface. Only on one occasion, July 27th, 1893, were simultaneous observations made with this instrument and Tornøe's electric apparatus, according to which its correction should be **+ 0·00027.**

[1] As before mentioned, these hydrometers had originally been supplied for the Norwegian North Atlantic Expedition in 1876. They are described by Hercules Tornøe in his Memoir on the salinity etc. of the Norwegian and Greenland Sea, see 'The Norwegian North Atlantic Expedition 1876—1878. Chemistry', Christiania, 1880, p. 47.

The Hydrometers Küchler Nos. 1, and 2.

These two instruments indicating from 1·000 to 1·007, and from 1·006 to 1·013, ($S\frac{t}{17{\cdot}5^\circ\,\mathrm{C.}}$) were used for determining the specific gravity of water-samples from the the upper strata of the sea. They have gone out again with Capt. Sverdrup, and I have had no opportunity of determining their corrections; but as the other hydrometers, delivered simultaneously by Küchler in 1876, for the Norwegian North Atlantic Expedition 1876—1878, have, as a rule, no greater corrections than 0·0002 and 0·0003, we cannot expect their corrections to have been much greater. The inaccuracy caused by supposing their errors to have been 0·0000 will therefore be of little importance as regards water of such low specific gravity, and varying so rapidly with the depth.

REDUCTION OF THE INDICATIONS OF THE GLASS HYDROMETER IN SEA-WATER OF t^0C., TO THE SPECIFIC GRAVITY $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$

For reducing the readings of the glass hydrometer at t^0 C. to 17·5^0 C. I have, for specific gravities above 1·0200, used the table calculated by Hercules Tornøe[1], as well as Krümmel's tables[2]. By constructing on a large scale the curves for these corrections, I have eliminated slight variations in Krümmel's figures, which are evidently erroneous, as they would make the curves too irregular. For sea-water where $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}} = 1{\cdot}0268$, I found Tornøe's corrections give more probable results than those of Krümmel, and my curve for this sea-water was therefore drawn nearer to Tornøe's figures.

As the surface-tension, $\alpha\,{}^{\mathrm{mg}}/_{\mathrm{mm}}$, of the sea-water varies with the temperature and the salinity, this will also cause variations in the indications of the hydrometer.

A difference in the salinity such as between 26·30 ‰ ($S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}} = 1{\cdot}0200$) 35·51 ‰ ($S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}} = 1{\cdot}0270$) of the sea-water will, however, only cause a difference in the surface-tension sufficient to change the indications of Åderman No. 2 about 0·000002, which is too slight to be considered.

[1] 'The Norwegian North Atlantic Expedition 1876—1878. Chemistry', p. 54.
[2] Krümmel, Ann. d. Hydr. u. Marit. Meteor. Heft X, October, 1890.

The temperature has somewhat more influence. For a water-sample with a specific gravity, $S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$, of 1·02662 (salinity = 35·0 ‰) I have calculated the weight of the meniscus surrounding the stem of Aderman No. 2 at various temperatures, provided that the surface-tension is at a maximum. I have also calculated what changes this meniscus will make in the indications of this hydrometer, the stem of which has a diameter of 4·4 mm. The distance between the division-marks is 0·823 mm., as stated on p. 146. The results of my calculations are given in the following table, for the temperatures 6° C., 10° C., 15° C., and 17·5° C. The surface-tension, $\alpha^{mg}/_{mm}$, at these temperatures should be 7·680, 7·609, 7·520, 7·475.[1]

Temperature of Sea-Water.	Weight of Meniscus $2\pi r\alpha$.	Volume by which this Weight will lower the Hydrometer.	Depth by which the Hydrometer is lowered.	Change caused by Surface-Tension in Indication of Hydrom.
° C.	mg.	mm^3	mm	
6	106·16	103·33	6·796	— 0·0008257
10	105·18	102·43	6·736	— 0·0008185
15	103·95	101·32	6·664	— 0·0008097
17·5	103·33	100·78	6·628	— 0·0008053

It will be seen that the difference between the surface-tension at 6° C. and 17·5° C. will cause a difference of 0·00002 in the indication of Åderman No. 2, which will read comparatively lower at 6° C. The correction for this temperature, when the indication of the hydrometer is to be referred to 17·5° C., ought therefore to be reduced accordingly.

I have accepted the corrections given in the following table for temperatures between 4° C. and 20° C. of sea-water with specific gravities, $S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$, of 1·0198, 1·0233 and 1·0268. The corrections given in the second column for each water-sample, are obtained by considering the variation of the indications of Åderman No. 2 caused by the variations of the surface-tension

[1] Cf. Memoir X, p. 26. The figures there given, on pp. 26 and 27, for the weight of the meniscus, etc., at 10°C. and 15°C. have by a mistake been stated too low. The correct figures for the same temperatures will be found in the above table.

with the temperature. For the Küchler hydrometers, these variations would be somewhat increased, as the diameter of the stem is greater.

Corrections for reducing the indications of Åderman No. 2 at t^0C. to 17·5°C.

t^0C.	$S\frac{17\cdot5^\circ C.}{17\cdot5^\circ C.} = 1\cdot0198$		$S\frac{17\cdot5^\circ C.}{17\cdot5^\circ C.} = 1\cdot0233$		$S\frac{17\cdot5^\circ C.}{17\cdot5^\circ C.} = 1\cdot0268$	
	Correction without considering changes of α mg/mm.	Correction considering changes in α mg/mm.	Correction without considering changes in α mg/mm.	Correction considering changes in α mg/mm.	Correction without considering changes in α mg/mm.	Correction considering changes in α mg/mm.
4	− 0·000175	− 0·000173	− 0·000190	− 0·000188	− 0·000200	− 0·000198
5	170	168	183	181	192	190
6	163	161	175	173	183	181
7	155	153	165	163	172	170
8	144	142	154	152	160	158
9	133	132	142	140	147	146
10	122	120	129	128	134	132
11	109	108	115	114	119	118
12	096	095	101	100	104	103
13	081	080	085	084	087	086
14	065	064	067	067	069	068
15	049	049	050	049	050	050
16	030	030	030	030	030	030
17	− 0·00010	− 0·00010	− 0·00010	− 0·00010	− 0·00010	− 0·00010
18	+ 0·00010	+ 0·00010	+ 0·00011	+ 0·00011	+ 0·00011	+ 0·00011
19	31	031	032	032	033	033
20	+ 51	+ 051	+ 054	+ 054	+ 056	+ 056

II.

OBSERVATIONS.

A. THE SPECIFIC GRAVITY OF THE WATER OF THE SEA-SURFACE.

The specific gravity of the water of the sea-surface was determined by Capt. Scott-Hansen with the Küchler and Åderman hydrometers. The water-samples were taken with a water-bucket, and in the ice sometimes also with a glass bottle. After the ship had become frozen in, the samples were generally taken in the water-hole kept open in the ice-floe some distance from the port side of the ship (see p. 63).

TABLE.

The columns of the following table give:

First column, Date of Observation.

Second column, Hour of Observation.

Third column, North Latitude of Observation.

Fourth column, Longitude East of Greenwich.

} Those marked by an *asterisk* are found by observations, the others are only approximately determined by dead reckoning.

Fifth column, Corrected Temperature of the Sea-surface (see Table, pp. 66 *et seq.*), referred to the indications of the Mercury Thermometer of 'verre dur'.

Sixth column, Corrected Temperature of the Water-Sample during the observation with the Hydrometer.

Seventh column, Designation of the Hydrometer used. *Å* means Åderman No. 1, or 2, and *K* means Küchler No. 1, 2, 3, or 4.

Eighth column, Reading of the Hydrometer, $S\frac{t}{17{\cdot}5^\circ\,\mathrm{C.}}$, before being corrected for instrumental error. For the sake of brevity, decimals only from the second to the fifth place are given, thus $1094 = 1{\cdot}01094$.

Ninth column, the Specific Gravity, $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$, of the water-sample obtained by correcting the Reading of the Hydrometer for Instrumental Error, and reducing the $S\frac{t}{17{\cdot}5^\circ\,\mathrm{C.}}$ thus found to $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$. For this reduction, I have used the tables of Admiral Makaroff[1]. Decimals from only the second to the fifth place are given, thus $1115 = 1{\cdot}01115$.

Tenth column, the Salinity per mille (i. e. grams of salt per 1000 grams of sea-water), corresponding to the $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$, found with the hydrometer. For this reduction, I have used the coefficient of 1315 found by Hercules Tornøe in 1893.[2] The salinity (per mille) $= 1315\left(S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}} - 1\right)$.

Eleventh column, Density, $S\frac{t}{4^\circ\,\mathrm{C.}}$, of the sea-water *in situ.*

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[1] Makaroff 'Le Vitiaz et l'Océan Pacifique' St. Petersbourg, 1894, pp. 116 *et seq.*

[2] H. Tornøe, 'Om Bestemmelse af Søvandets Saltgehalt ved Hjælp af dets elektriske Ledningsevne'. Nyt Magazin for Naturvidenskaberne, Christiania, 1893, separate copy, p. 5.

TABLE

SHOWING THE TEMPERATURE, SPECIFIC GRAVITY, SALINITY, AND DENSITY OF THE WATER OF THE SEA-SURFACE.

OBSERVATIONS MADE BY CAPT. SIGURD SCOTT-HANSEN.

Date.	Hour.	North Lat.	East Long.	Corr. Temp. of Sea-Surf.	Corr. Temp. of Wat. Samp.	Designation of Hydrom.	Reading of Hydrometer.	$S\,\frac{17.5^\circ C.}{17.5^\circ C.}$	Salinity	$S\,\frac{t}{4^\circ C.}$
1893.				° C.	° C.				‰	
Aug. 12	6 p.m.	72° 58′	68° 38′	3·35	19·5	Å 1	1094	1·01169	15·37	1·01222
- 17	10 -	75 10	80 20	1·53	17·2	-	1130	1165	15·32	1223
- 18	8 a.m.	*74 43	*80 16	0·9	20·9	-	0966	1071	14·09	1124
- -	2 p.m.	74 18	80 37	2·05	5·7	-	0905	0815	10·72	0852
- -	4 -	74 10	80 39	2·1	10·1	-	0910	0854	11·23	0891
- -	8 -	73 59	80 42	1·5	9·2	-	1250	1169	15·37	1227
- 19	8 a.m.	*73 43	*81 10	—0·1	18·9	K 3	1750	1805	23·74	1898
- -	Noon	*73 56	81 26	0·1	17·5	-	1220	1247	16·40	1308
- -	4 p.m.	74 7	82 12	0·0	11·1	- 4	1860	1729	22·73	1818
- -	8 -	74 13	82 45	0·8	7·1	- 3	1490	1385	18·21	1454
- -	11 -	74 22	82 56	2·45	17·4	- 2	0920	0918	12·07	0961
- 20	4 a.m.	74 43	83 21	0·9	20·0	-	0928	0974	12·81	1020
- -	8 -	74 58	83 44	1·3	15·3	- 1	0615	0582	7·65	0608
- -	Noon	*74 59·5	84 22	3·2	5·1	-	0582	0476	6·26	0497
- -	5 p.m.	74 52	85 30	3·0	8·1	-	0548	0449	5·90	0469
- -	5·15 -	74 52	85 30	3·0	9·3	-	0540	0448	5·89	0468
- -	6 -	74 50	85 42	2·9	6·3	-	0458	0356	4·68	0372
- 21	8 a.m.	*74 48	*85 33	2·65	14·1	-	0498	0451	5·93	0473
- -	Noon	*74 46	*85 33	2·5	3·4	-	0600	0492	6·47	0514
- 22	8 p.m.	74 46	85 33	1·0	10·4	- 4	1816	1678	22·07	1762
- 24	8 -	75 44	84 40	—1·1	6·0	Å 2	2547	2435	32·02	2585
- 25	Noon	75 38	85 17	—0·9	9·1	K 4	2117	1951	25·66	2054
- -	4 p.m.	*75 27·2	*85 30	—0·4	6·4	-	2297	2101	27·63	2211
- -	8 -	75 20	86 17	—0·8	19·6	-	2238	2248	29·56	2366
- 26	8 a.m.	*75 25	*87 44	—1·2	14·9	Å 2	2555	2562	33·69	2700
- -	Noon	75 24	88 26	—1·3	0·6	-	2709	2561	33·68	2699
- -	4 p.m.	75 39	88 14	—1·0	17·2	K 4	2155	2121	27·90	2233
- -	8 -	75 37	89 14	—0·8	17·1	-	2100	2064	27·14	2173
- 27	8 a.m.	*75 58	*91 27	—0·8	8·9	Å 2	2586	2499	32·86	3531
- -	Noon	*76 6	*92 17	—0·9	10·5	K 4	2040	1899	24·96	1997
- -	4 p.m.	76 10	92 33	—0·1	5·7	- 2	0957	0837	11·01	0873
- -	8 -	76 12	94 6	—0·6	3·4	- 3	1313	1201	15·76	1258
- 28	4 a.m.	76 33	94 0	—1·0	6·5	-	1660	1546	20·33	1623
- -	Noon	*76 46	*94 32	—0·6	12·1	- 4	1929	1811	23·82	1905
- -	4 p.m.	*76 54	*95 2	—0·5	5·9	- 1	0182	0088	1·16	0077
- 29	4 a.m.	76 37	93 48	—0·7	1·8	- 3	1599	1474	19·38	1547
- -	Noon	*76 28	*94 30	0·0	10·2	- 2	1060	0963	12·66	1008
- -	4 p.m.	76 27	95 30	—0·05	2·0	-	0745	0633	8·32	0658

Date.	Hour.	North Lat.	East Long.	Corr. Temp. of Sea-Surf.	Corr. Temp. of Wat. Samp.	Designation of Hydrom.	Reading of Hydrometer.	$S\frac{17{\cdot}5^\circ C.}{17{\cdot}5^\circ C.}$	Salinity	$S\frac{t}{4^\circ C.}$
1893.				° C.	° C.				‰	
Aug 29	8 p.m.	76° 28′	96° 30′	−0·4	6·6	K 2	0870	1·00756	9·94	1·00787
- -	Midn.	76 27	96 39	−0·5	13·9	-	0776	0722	9·49	0750
- 30	8 a.m.	76 25	96 27	−0·1	9·7	- 1	0612	0521	6·85	0548
- -	Noon	76 25	96 27	0·0	1·7	-	0470	0373	4·91	0383
- -	4 p m.	*76 25	*96 27	−0·1	1·1	-	0455	0362	4·76	0371
- -	8 -	76 25	96 27	−0·1	7·6	-	0477	0378	4·97	0389
- -	Midn.	76 25	96 27	−0·35	1·9	-	0455	0358	4·71	0366
- -	Noon	76 25	96 27	-	2·4	-	0460	0362	4·76	0370
- 31	8 a.m.	76 25	96 27	−0·2	11·0	-	0440	0362	4·76	0370
- -	Noon	76 25	96 27	−0·1	2·1	-	0450	0351	4·62	0359
- -	4 p.m.	76 25	96 27	−0·1	2·5	-	0460	0361	4·75	0370
- -	8 p.m.	76 25	96 27	−0·1	9·3	-	0458	0368	4·84	0377
- -	Midn.	76 25	96 27	−0·1	9·8	-	0454	0367	4·83	0376
Sept. 1	4 a.m.	76 25	96 27	−0·3	9·0	-	0460	0368	4·84	0376
- -	8 -	*76 25	*96 27	−0·15	4·8	-	0450	0347	4·56	0354
- -	Noon	76 25	96 27	−0·1	8·4	-	0457	0362	4·76	0371
- -	8 p.m.	76 25	96 27	−0·1	2·5	-	0470	0371	4·88	0380
- 2	4 a.m.	76 25	96 27	−0·3	8·8	-	0456	0363	4·77	0371
- -	8 -	76 25	96 27	−0·15	1·9	-	0460	0364	4·79	0371
- -	Noon	76 25	96 27	−0·25	4·7	-	0580	0473	6·22	0487
- -	4 p.m.	76 25	96 27	−0·2	4·7	-	0557	0451	5·93	0464
- -	8 -	76 25	96 27	−0·2	2·5	-	0460	0361	4·75	0368
- 3	8 a.m.	76 22	95 57	−0·4	3·5	- 2	0680	0569	7·48	0588
- -	Noon	76 9	95 22	−0·4	2·3	-	1020	0896	11·78	0935
- -	4 p.m.	76 15	95 10	−0·2	4·6	-	0985	0861	11·32	0899
- -	8 -	76 13	95 6	−0·25	1·3	-	0977	0856	11·26	0893
- 4	8 a.m.	76 13	95 6	−0·4	11·9	-	0690	0616	8·10	0638
- -	Noon	76 13	95 6	−0·4	12·6	-	0653	0586	7·71	0606
- -	4 p.m.	76 13	95 6	−0·35	12·7	-	0670	0604	7·94	0626
- -	9 -	76 13	95 6	−0·4	9·2	-	0720	0623	8·19	0644
- -	Midn.	76 13	95 6	−0·4	8·9	-	0820	0719	9·45	0746
- 5	8 a.m.	76 13	95 6	−0·75	5·8	- 3	1397	1288	16·94	1350
- -	Noon	76 13	95 6	−1·2	6·6	- 4	2070	1889	24·85	1988
- -	4 p.m.	76 13	95 6	−1·2	8·0	-	2090	1921	25·27	2022
- -	8 -	76 13	95 6	−1·25	5·8	-	2130	1941	25·53	2043
- 6	4 a.m.	76 13	95 6	−1·3	6·8	-	2195	2012	26·46	2118
- -	8 -	76 13	95 6	−1·3	4·3	-	2335	2131	28·02	2244
- -	Noon	*76 8·7	*94 22	−1·4	0·0	-	2355	2137	28·10	2251
- -	4 p.m.	76 9	94 22	−1·45	4·8	-	2308	2108	27·72	2220
- -	8 -	76 20	95 18	−0·8	2·4	-	1295	1129	14·85	1180
- -	Midn.	76 24	96 15	−1·6	14·7	-	1840	1762	23·17	1852
- 7	4 a.m.	76 31	97 24	−1·4	14·8	-	1948	1870	24·59	1967
- -	8 -	*76 27·7	*98 14	−1·0	13·3	- 3	1577	1534	20·17	1610
- -	Noon	*76 32	*98 35	0·6	12·2	- 1	0530	0462	6·08	0479
- -	4 p.m.	76 33	99 45	−0·6	6·8	- 3	1475	1369	18·00	1436
- -	8 -	76 32	100 38	−0·6	9·8	-	1313	1234	16·23	1293
- -	Midn.	*76 32	*100 40	0·9	16·9	- 2	1160	1150	15·12	1206
- 8	4 a.m.	76 32	100 40	−0·9	17·0	-	1145	1137	14·95	1189

Date.	Hour.	North Lat.	East Long.	Corr. Temp. of Sea-Surf.	Corr. Temp. of Wat. Samp.	Designation of Hydrom.	Reading of Hydrometer.	$S\frac{17{\cdot}5^\circ C.}{17{\cdot}5^\circ C.}$	Salinity	$S\frac{t}{4^\circ C.}$
1893.				°C.	°C.				°/₀₀	
Sept. 8	8 a.m.	76° 33′	100° 40′	0·7	17·7	K 2	1120	1·01123	14·77	1·01177
- -	Noon	76 32	100 40	—0·4	12·4	- 3	1270	1220	16·04	1278
- -	4 p.m.	76 32	100 40	—0·6	11·9	- 2	1210	1128	14·83	1181
- -	8 -	76 36	100 49	—0·8	2·9	- 3	1428	1311	17·24	1375
- -	Midn.	76 36	100 49	—0·7	20·4	-	1235	1319	17·35	1383
- 9	4 a.m.	76 36	100 49	—0·9	18·8	-	1225	1277	16·79	1338
- -	8 -	76 36	100 49	—0·6	13·4	-	1335	1298	17·07	1361
- -	Noon	*76 56	100 54	—0·6	19·9	- 4	1925	1946	25·59	2048
- -	4 p.m.	77 21	101 33	—1·1	11·1	-	2188	2051	26·97	2159
- -	-	77 21	101 33	-	17·3	-	2170	2138	28·11	2251
- -	8 -	77 34	101 18	—1·1	5·8	-	2395	2198	28·90	2314
- 10	4 a.m.	77 49	104 20	—1·1	16·55	-	2055	2009	26·42	2115
- -	8 -	*77 42	*105 8	—0·6	16·7	-	2054	2010	26·43	2117
- -	Noon	*77 36	*106 3	—1·2	14·4	-	1995	1911	25·13	2013
- -	4 p.m.	77 30	106 36	—1·1	7·7	-	2153	1978	26·01	2082
- -	8 -	77 30	106 44	—1·1	5·8	-	2155	1964	25·83	2067
- -	Midn.	77 9	107 36	—1·3	16·3	-	2019	1968	25·88	2072
- 11	8 a.m.	76 56	110 8	—0·8	18·6	-	2140	2134	28·07	2247
- -	Noon	*76 58	*111 32	—1·2	8·8	-	2397	2264	29·77	2387
- -	8 p.m.	76 48	113 20	—1·2	5·9	-	2400	2204	28·98	2321
- -	Midn.	76 32	113 8	0·9	15·9	-	2394	2334	30·69	2451
- 12	4 a.m.	76 17	113 49	—1·6	18·5	-	2330	2322	30·53	2446
- -	8 -	76 8	113 59	—1·55	14·8	-	2375	2295	30·18	2417
- -	Noon	*76 2	*114 12	—1·45	19·3	-	2280	2290	30·11	2412
- -	4 p.m.	75 50	114 23	—1·6	12·7	-	2408	2293	30·16	2415
- -	8 -	75 38	114 26	—1·6	4·0	-	2418	2210	29·06	2327
- -	Midn.	75 26	115 10	—0·6	11·1	-	1940	1808	23·78	1902
- 13	4 a.m.	75 16	115 44	—1·1	11·9	-	1960	1837	24·16	1930
- -	8 -	74 59	115 28	—1·0	9·8	- 3	1535	1451	19·07	1522
- -	Noon	*74 55	*116 0	—0·6	4·0	-	1368	1245	16·38	1305
- -	4 p.m.	74 55	115 2	—0·1	6·9	-	1305	1205	15·85	1263
- -	8 -	74 38	114 53	—0·4	13·7	-	1260	1225	16·11	1284
- -	Midn.	74 26	115 13	—0·6	10·3	-	1418	1390	18·28	1458
- 14	4 a.m.	74 28	114 54	—0·8	10·9	-	1448	1431	18·82	1502
- -	8 -	74 23	113 50	—0·5	7·4	-	1485	1382	18·18	1450
- -	Noon	74 4	114 10	—0·5	4·3	-	1593	1471	19·34	1544
- -	4 p.m.	*73 49	114 7	0·0	9·5	-	1320	1238	16·29	1299
- -	8 -	*73 43	115 3	0·05	4·9	-	1355	1245	16·38	1306
- -	Midn.	73 43	115 46	0·0	16·2	-	1265	1269	16·73	1331
- 15	4 a.m.	73 45	115 52	—0·2	15·5	-	1290	1283	16·88	1346
- -	8 -	73 55	116 51	—0·1	10·3	-	1486	1408	18·52	1478
- -	Noon	73 52	117 17	—0·1	12·3	-	1480	1425	18·74	1496
- -	4 p.m.	*73 53	*117 50	0·8	10·0	-	1538	1456	19·13	1529
- -	8 -	73 53	118 46	1·4	12·9	-	1678	1629	21·42	1709
- -	Midn.	74 3	119 34	2·0	14·9	-	1672	1653	21·74	1733
- 16	4 a.m.	74 13	120 20	1·8	15·1	-	1470	1456	19·13	1527
- -	8 -	*74 20	*121 15	1·9	11·1	-	1648	1476	20·73	1653
- -	Noon	*74 27	*122 9	1·55	14·8	-	1768	1746	22·96	1832

Date.	Hour.	North Lat.	East Long.	Corr. Temp. of Sea-Surf.	Corr. Temp. of Wat. Samp.	Designation of Hydrom.	Reading of Hydrometer.	$S\frac{17{\cdot}5^\circ C.}{17{\cdot}5^\circ C.}$	Salinity.	$S\frac{t}{4^\circ C.}$
1893.				° C.	° C.				‰	
Sept. 16	4 p.m.	74° 34′	123° 21′	0·9	6·4	K 3	1582	1·01417	19·32	1·01544
- -	8 -	74 42	124 26	1·0	5·2	- 2	1105	0977	12·85	1024
- -	Midn.	74 50	125 25	0·6	17·55	-	0925	0926	12·18	0969
- 17	8 a.m.	74 51	127 34	−0·05	7·9	-	1095	0980	12·89	1026
- -	Noon	*74 52	*128 50	−0·35	13·55	-	1036	0976	12·83	1021
- -	4 p.m.	*75 2	*130 0	−0·35	4·3	-	1218	1084	14·25	1135
- -	8 -	75 1	131 4	−0·4	15·1	- 3	1275	1262	16·62	1323
- -	Midn.	74 41	131 35	0·4	14·9	- 2	1135	1083	14·24	1135
- 18	4 a.m.	74 39	131 35	0·4	15·2	-	1060	1023	13·45	1071
- -	8 -	74 38	132 47	−0·08	12·6	-	1058	0986	12·97	1031
- -	Noon	74 35	134 0	−0·14	2·6	- 3	1230	1121	14·74	1174
- -	4 p.m.	*74 50	*134 38	−0·65	18·1	- 2	1175	1186	15·60	1242
- -	8 -	*75 8	*135 15	−0·5	6·6	- 3	1275	1174	15·44	1229
- -	Midn.	75 24	134 46	−0·81	16·9	-	1255	1271	16·71	1332
- 19	4 a.m.	75 32	134 21	−0·5	16·3	- 2	1155	1134	14·91	1187
- -	8 -	75 48	134 14	−0·65	15·6	- 3	1280	1275	16·77	1337
- -	Noon	*76 3	*134 37	−0·7	19·65	-	1324	1392	18·30	1461
- -	4 p.m.	*76 21	*135 13	−0·6	14·15	-	1403	1375	18·08	1443
- -	8 -	76 42	136 14	−0·6	17·7	-	1649	1678	22·07	1765
- -	Midn.	77 0	136 54	−0·4	14·0	- 4	1895	1805	23·73	1898
- 20	4 a.m.	77 15	137 38	−0·5	11·6	-	2070	1942	25·54	2044
- -	8 -	77 33	138 19	−0·95	1·3	-	2296	2083	27·39	2194
- -	Noon	*77 46	138 42	−1·4	15·1	-	2155	2081	27·36	2191
- -	4 p.m.	*77 52	*137 0	−1·4	13·9	-	2155	2061	27·10	2170
- -	8 -	78 2	136 6	−1·4	15·2	-	2145	2074	27·27	2184
- -	Midn.	78 10	135 13	−1·5	18·9	-	2120	2121	27·89	2234
- 21	4 a.m.	78 17	134 23	−1·2	18·3	-	2218	2206	29·00	2323
- -	8 -	78 34	133 52	−1·6	14·2	-	2205	2116	27·82	2229
- -	1·15 p.m.	78 40	133 3	−1·77	3·4	-	2445	2230	29·32	2349
- -	4 -	78 41	133 0	−1·7	13·9	-	2318	2223	29·23	2342
- -	8	*78 39	*133 10	−1·7	5·9	-	2456	2258	29·69	2379
- -	Midn.	78 42	133 26	−1·7	12·7	-	2383	2268	29·82	2389
- 22	4 a.m.	78 43	133 45	−1·6	14·8	-	2360	2280	29·98	2402
- -	8 -	*78 49	*132 54	−1·7	9·95	-	2430	2276	29·93	2397
- -	Noon	78 51	133 0	−1·7	11·8	-	2418	2289	30·10	2411
- -	5·30 p.m.	*78 42	*133 35	−1·7	0·9	-	2435	2213	29·10	2331
- -	8 -	78 43	133 30	−1·7	3·6	-	2425	2214	29·11	2332
- -	Midn.	78 43	133 25	−1·8	17·1	-	2273	2237	29·41	2357
- 23	4 a.m.	78 44	133 20	−1·8	14·95	-	2308	2232	29·35	2353
- -	8 -	78 45	133 14	−1·75	17·2	-	2280	2246	29·53	2366
- -	Noon	78 46	133 9	−1·7	14·95	-	2325	2249	29·57	2369
- -	8 p.m.	78 47	132 59	−1·7	2·9	-	2434	2219	29·17	2338
- -	Midn.	78 48	132 54	−1·7	18·5	-	1990	1982	26·06	2086
- 24	4 a.m.	78 49	132 48	−1·65	18·0	-	2178	2160	28·40	2275
- -	8 -	78 50	132 43	−1·6	17·9	-	2202	2182	28·69	2298
- -	8·20 p.m.	*78 51	132 27	−1·7	5·4	-	2440	2240	29·45	2366
- 25	4 a.m.	78 51	132 21	−1·8	11·9	Å 2	2265	2224	29·25	2343
- -	8 -	78 51	132 20	−1·75	6·0	-	2399	2290	30·11	2413

Date.	Hour.	North Lat.	East Long.	Corr. Temp. of Sea-Surf.	Corr. Temp, of Wat. Samp.	Designation of Hydrom.	Reading of Hydrometer.	$S\frac{17.5^\circ C.}{17.5^\circ C.}$	Salinity.	$S\frac{t}{4^\circ C.}$
1893.				° C.	° C.				‰	
Sept. 25	1 p.m.	78° 51′	132° 18′	—1·7	9·1	Å 2	2336	1·02258	29·69	1·02379
- -	4 -	78 51	132 18	—1·7	10·9	-	2423	2367	31·13	2494
- -	8 -	78 50	132 17	—1·8	14·7	-	2284	2289	30·10	2411
- -	Midn.	78 50	132 16	—1·8	15·5	-	2465	2483	32·65	2617
- 26	4 a.m.	78 50	132 15	—1·8	14·5	-	2189	2191	28·81	2308
- -	Noon	*78 50	*132 9	—1·7	12·9	-	2289	2264	29·77	2385
- 27	-	78 52	132 4	—1·8	10·9	-	2320	2266	29·79	2387
- 28	1 p.m.	78 56	131 55	—1·7	8·2	-	2397	2308	30·35	2431
- 29	Noon	*79 0	*131 46	—1·8	17·15	-	2268	2319	30·49	2443
- 30	-	78 58	132 41	—1·8	11·6	-	2359	2313	30·42	2437
Oct. 1	-	78 55	133 38	—1·8	12·95	-	2350	2325	30·57	2450
- 2	-	*78 53	*134 34	—1·75	8·9	-	2377	2296	30·19	2419
- 3	-	*78 49	135 11	—1·73	7·8	-	2419	2326	30·59	2451
- 4	-	78 44	135 33	—1·7	7·8	-	2308	2218	29·17	2337
- 5	-	78 38	135 56	—1·65	17·1	-	2087	2137	28·10	2251
- 8	-	*78 24	*136 4	—1·6	14·5	-	2147	2150	28·27	2265
- 9	3 p.m.	78 21	136 4	—1·6	7·7	-	2216	2127	27·97	2241
- 11	Noon	78 17	136 0	—1·6	8·4	-	2206	2124	27·93	2237
- 12	-	*78 14	*135 58	—1·6	10·9	-	2166	2113	27·79	2226
- 14	-	78 15	136 3	—1·75	3·7	-	2195	2079	27·34	2190
- 19	4 p.m.	*78 19	*136 17	—1·6	7·0	-	2176	2081	27·37	2192
- 20	Noon	78 19	136 9	—1·6	1·7	-	2195	2072	27·25	2182
- 21	-	78 18	135 56	—1·6	6·6	-	2134	2037	26·79	2145
- 22	4 p.m.	78 18	135 42	—1·7	4·5	-	2116	2007	26·40	2113
- 23	3 -	*78 17	*135 29	—1·5	16·0	K 4	1995	1938	25·48	2039
- 24	Noon	78 20	135 37	—1·55	4·2	-	2159	1961	25·78	2064
- 25	-	78 26	135 52	—1·45	16·9	-	2450	2410	31·69	2539
- 26	-	*78 31	*136 8	—1·5	6·9	-	2250	2067	27·18	2177
- 27	-	78 28	136 2	—1·68	12·5	-	2142	2028	26·67	2137
- 28	-	*78 21	*135 49	—1·5	9·5	-	2135	1981	26·04	2085
- 29	-	78 18	135 39	—1·5	4·9	Å 2	2120	2013	26·48	2120
- 30	-	*78 15	*135 31	—1·4	13·8	K 4	2203	2107	27·71	2219
Nov. 1	-	*78 4	*134 56	—1·4	9·5	-	2219	2063	27·13	2172
- 2	-	*78 2	*134 53	—1·45	16·9	-	2022	1982	26·05	2086
- 3	-	*78 2	*134 56	—1·5	18·9	-	2325	2322	30·47	2441
- 4	-	77 59	135 30	—1·5	8·9	-	2148	1986	26·11	2091
- 5	1 p.m.	77 56	136 16	—1·45	10·6	-	2185	2042	26·86	2150
- 6	Noon	77 53	136 59	—1·5	7·5	-	2250	2073	27·25	2183
- 7	-	*77 51	*137 44	—1·5	8·3	-	2305	2133	28·05	2246
- 8	-	77 52	137 54	—1·55	4·8	-	2335	2134	28·06	2247
- 9	-	77 54	137 52	—1·5	7·2	-	2335	2153	28·30	2267
- 10	-	*77 57	*137 50	—1·65	12·8	-	2278	2165	28·47	2280
- 11	-	77 58	137 58	—1·5	10·1	-	2305	2154	28·32	2268
- 12	-	78 0	138 10	—1·55	6·9	Å 2	2308	2209	29·05	2327
- 13	-	*78 2	*138 22	—1·55	9·6	K 4	2338	2181	28·68	2297
- 14	-	78 6	138 34	—1·6	7·4	-	2407	2224	29·25	2343
- 15	-	78 12	138 47	—1·55	8·0	Å 2	2275	2187	28·76	2304
- 16	-	*78 18	*139 0	—1·65	3·9	-	2360	2139	28·13	2253

Date.	Hour.	North Lat.	East Long.	Corr. Temp. of Sea-Surf.	Corr. Temp. of Wat. Samp.	Designation of Hydrom.	Reading of Hydrometer.	$S\frac{17{\cdot}5^\circ C.}{17{\cdot}5^\circ C.}$	Salinity.	$S\frac{t}{4^\circ C.}$
1893.				° C.	° C.				‰	
Nov. 18	Noon	*78° 25′	139° 16′	−1·6	13·4	Å 2	2245	1·02228	29·30	1·02347
- 19	-	78 24	139 17	−1·7	9·4	-	2302	2231	29·34	2351
- 20	-	*78 24	*139 17	−1·65	9·2	-	2283	2209	29·05	2327
- 22	-	*78 26	*139 24	−1·65	10·2	-	2282	2221	29·21	2340
- 28	-	*78 39	*138 55	−1·55	3·5	-	2372	2249	29·57	2369
- 29	-	78 40	138 49	−1·5	12·5	-	2236	2206	29·01	2323
- 30	-	78 41	138 42	−1·69	10·2	-	2235	2174	28·59	2290
Dec. 1	-	*78 42	*138 36	−1·72	10·7	-	2238	2182	28·69	2299
- 3	-	78 45	138 19	−1·62	10·8	-	2232	2178	28·64	2295
- 5	-	*78 51	*137 53	−1·67	4·8	-	2170	2059	29·70	2169
- 6	-	78 52	137 46	−1·62	8·3	-	2199	2116	27·83	2229
- 7	-	78 54	137 42	−1·62	4·5	-	2238	2124	27·93	2237
- 8	-	*78 56	*137 37	−1·62	10·6	-	2160	2106	27·70	2218
- 20	-	*79 7	*137 28	−1·72	6·8	-	2192	2095	27·55	2207
- 21	-	*79 7	*137 21	−1·49	6·7	-	2200	2103	27·66	2215
1894.										
Jan. 23	11 a.m.	*79 42	*135 36	−1·62	8·8	-	2295	2215	29·13	2334
- 28	Noon	*79 45	*134 46	−1·57	11·6	-	2205	2161	28·42	2277
- 29	3 p.m.	*79 45	*134 44	−1·55	13·8	-	2187	2177	28·63	2293
Feb. 1	3 p.m.	*79 55	*134 22	−1·57	6·3	-	2295	2192	28·82	2310
- 3	Noon	*79 59	*134 21	−1·6	10·7	-	2273	2217	29·16	2336
- 5	-	*79 57	*134 37	−1·6	11·2	-	2250	2200	28·92	2318
- 14	11 a.m.	*80 0	*134 2	−1·6	13·2	-	2255	2234	29·37	2354
- 16	-	*80 3	133 53	−1·6	13·5	-	2210	2197	28·89	2315
. 19	-	*80 2	*133 50	−1·6	6·4	-	2275	2173	28·56	2289
- 21	-	*80 6	*133 55	−1·65	6·7	-	2300	2200	28·92	2318
- 28	Noon	80 0	134 24	−1·65	9·7	-	2370	2299	30·24	2422
March 5	-	*79 54	*134 46	−1·65	7·2	-	2350	2253	29·63	2374
- 8	-	*79 48	*134 9	−1·65		-	2325			
- 12	-	*79 41	*134 14	−1·6	10·2	-	2335	2272	29·88	2394
- 15	11 a.m.	*79 39	*134 56	−1·61	9·0	-	2300	2222	29·22	2341
- 19	-	*79 39	*135 12	−1·6	9·2	-	2265	2190	28·80	2307
- 24	-	*80 1	*134 43	−1·61	11·2	-	2305	2255	29·65	2376
- 30	-	*80 9	134 59	−1·61	10·2	-	2305	2242	29·48	2362
April 3	Noon	*80 9	*134 57	−1·63	9·8	-	2335	2266	29·79	2387
- 10	11 a.m.	*80 17	134 33	−1·63	8·5	-	2340	2256	29·66	2377
- 16	Noon	*80 16	*133 10	−1·61	10·7	-	2300	2243	29·49	2363

B. THE SPECIFIC GRAVITY OF THE SERIAL WATER-SAMPLES TAKEN FROM THE BARENTS SEA AND THE NORTH POLAR BASIN.

The specific gravity of the serial water-samples were determined with the hydrometer by myself in 1893 and 1894. On July 23rd, 27th and 28th, the observations were, with few exceptions, made by Capt. S. Scott-Hansen. In 1895 all observations with the hydrometer were made by Dr. G. Blessing.

My method of making the observations is described above (pp. 143 *et seq*). Blessing's method of observing differed but little from mine, and gave very similar results. It is described in a later chapter headed: 'Remarks on the accuracy of the determinations.' The water-samples mentioned in the following table were taken with Pettersson's water-bottle until April 6th, 1895, when it was lost. After that date, they were taken with Blessing's water-bottle.

TABLE.

The columns in the following table give:

First column. The distinguishing Number of the Temperature-Series; see Table, pp. 108 *et seq.*

Second column. The Date when the Water-sample was taken; in some few cases also the Hour. The Dates when the Determinations with the Hydrometer were made are given between brackets. Under the Dates are given, first the North Latitude (marked N), and beneath it the Longitude East of Greenwich (marked E).

Third column. The Depth, in Metres, from which the water-sample was taken.

Fourth column. Designation of the Thermometer by which the Temperature of the Water-Sample was determined. *S* 16, *S* 20, *S* 25 = Söderberg Nos. 16, 20, and 25 (corrections, see pp.59, 60); *KI* = Küchler No. I (correction, see p. 29); *M.* 4, *M.* 6, and *M.* 7 = F. Müller Nos. 4, 6, and 7 (corrections, see pp. 37, 35, 32); *Gr.* = the thermometer R. Grave (correction, see p. 38). *Ca.* = Casella No. 72327 (correction, see p. 62).

The thermometers Müller Nos. 4, 6 and 7 were immersed in the water to take the Temperature, and again removed between each Reading of the Hydrometer. The other thermometers were hanging continuously in the water during each series of observations.

Fifth column. The Temperature of the Water-Sample, which has been corrected for the instrumental Error of the Thermometer.

Sixth column. Reading of the Hydrometer. Decimals from only the second to the fifth place are given, *e. g.* 2700 = 1·02700.

An *asterisk* before the figures indicate that the observation was made with one of the Küchler Hydrometers; the number of the instrument may be gathered from the indication. The Readings without an asterisk are all taken with Åderman No. 2, and if the Reading is below 1·01500, with Åderman No. 1.

Seventh column. The Reading of the Hydrometer referred to 17·5° C. according to the Table given on p. 155. 2536 = 1·02536. Under the series of observations of each water-sample, is given the mean of all the observations.

Eighth column. The Correction of the Instrument. The mean of the observations of each water-sample is corrected with the mean instrumental correction, while maximum and minimum indications are corrected with minimum and maximum corrections (see explanation, pp. 149 to 151).

Ninth column. The Specific Gravity, $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$, of the Water-Sample. The Specific Gravities obtained by correcting the mean results of each series of observations, are to be considered as the final results, while those obtained by correcting with minimum and maximum corrections are to be considered as lower and upper limits (see explanation, pp. 149 to 151).

Tenth column. Salinity per mille (*i. e.* grams of salt per 1000 grams of sea-water) corresponding to the obtained $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$. The salinity is found by the formula $\left(S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}} - 1\right) 1315$ (see p. 157).

TABLE

SHOWING THE DETERMINATIONS OF THE SPECIFIC GRAVITIES, $\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$, OF THE WATER OF THE BARENTS SEA AND THE NORTH POLAR BASIN.

MADE BY NANSEN FROM JULY, 1893, TO DECEMBER, 1894, AND BY BLESSING FROM APRIL, 1895, TO DECEMBER, 1895.[1]

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1893.	m.		° C.					‰
1	July 22	0	*S* 25	7·5	2700	2538	+ 55	1·02593	34·10
	9·45 p.m.	20	—	13·35	2688	2609	—	1·02664	35·03
	70° 43′ N	40	—	12·75	2698	2609	—	1·02664	35·03
	39 35 E	60	—	12·3	2704	2607	—	1·02662	35·01
		80	—	11·1	2722	2606	—	1·02661	34·99
		100	—	10·5	2731	2606	—	1·02661	34·99
		150	—	8·3	2852	2698	+ 54	1·02752?	
		200	—	4·95	2810	2620	—	1·02674	35·16
2	July 23	0[2]	*M* 4	6·37	2745	2570	+ 55	1·02625	34·52
	9·15 p.m.	0[3]	—	6·17	2743	2567	—	1·02622	34·48
	71° 3′ N	20	—	12·15	2679	2579	—	1·02634	34·64
	43 31 E	40	—	12·1	2687	2586	—	1·02641	34·73
		60	—	12·13	2693	2593	—	1·02648	34·82
		80	—	12·1	2700	2599	—	1·02654	34·90
		100	—	12·0	2705	2603	—	1·02658	34·95
		130	—	3·35	2798	2597	—	1·02652	34·87
		130	—	4·3	2794	2600	—	1·02655	34·91
3	July 24	20	*M* 4	8·45	2713	2562	+ 55	1·02617	34·41
	10 p.m.	80	—	10·3	2722	2596	—	1·02651	34·86
5	July 27	0	*K.* I	15·06	*1795	1749	+ 27	1·01776	23·35
	0·20 p.m.	5	—	14·04	*2245	2181	— 27	1·02154	28·32
	69° 43′ N	10	—	14·96	2305	2254	+ 57	1·02311	30·39
	54 23 E	14·5	—	14·65	2590	2533	+ 55	1·02588	34·03
		20	—	14·86	2612	2559	—	1·02614	34·37
		30	—	14·57	2637	2579	—	1·02634	34·64
		40	—	14·97	2635	2584	—	1·02639	34·70
		50	—	14·97	2638	2587	—	1·02642	34·74

[1] The determinations from July 23d to 28th, 1893, were, with few exceptions, made by Capt. S. Scott-Hansen.

[2] Water-sample taken with water-bucket.

[3] Water-sample taken with Pettersson's water-bottle.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydro-meter.	Reading referred to 17·5° C.	Correc-tion.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1893.	m.		° C.					‰
6	July 28	5	*S*?	13·6	2425	2352	+ 57	1·02409	31·68
	9 p.m.	10	—	12·35	2630	2534	+ 55	1·02589	34·05
	69° 25′ N	15	—	12·30	2635	2538	—	1·02593	34·10
	57 7 E	20	—	12·1	2658	2558	—	1·02613	34·36
		22							
7	Aug. 11	0	*S* 16	19·2	1387	1420	+ 40	1·01460	19·19
	Noon	5	—	19·4	2216	2256	+ 58	1·02314	30·43
	71° 21′ N	10	—	19·8	*2010	2057	— 27	1·02030	26·68
	66 24 E	15	—	20·0	2295	2348	+ 57	1·02405	31·63
		20	—	19·65	2357	2404	—	1·02461	32·36
		24	—	19·95	2368	2422	—	1·02479	32·60
		26·5							
9	Oct. 9	20	?	9·8	*2392	2262	— 27	1·02235	29·39
	Noon	120	?	9·9	*2731	2597	—	1·02570	33·80
	[Oct. 17]	145	?	10·9	*2746	2627	—	1·02600	34·19
	78° 20′ N								
	136 0 E								
	1894.								
14	April 14	0·5	*S* 20	6·2	*2482	2313	— 27	1·02286	
	[April 18]		—	7·2	2387	2228	+ 57	1·02285	
	80° 12′ N		—	7·8	*2457	2305	— 27	1·02278	
	133 50 E							1·02283	30·02
	April 21	1[1]	*S* 20	7·1	2348	2189	+ 57	1·02246	
	[April 21]		—	7·5	2345	2191	—	1·02248	
			—	8·3	*2423	2278	— 27	1·02251	
			—	8·5	*2419	2276	—	1·02249	
			—	9·8	2329	2201	+ 57	1·02258	
								1·02250	29·58
	April 14	20	—	7·8	*2443	2289	— 27	1·02262	29·74
	[April 18]	40[2]	—	10·5	2453	2332	+ 56	1·02388	31·39
	[April 21]	60	—	8·9	2629	2485	+ 55	1·02540	33·40

[1] The specific gravity found for this depth is not quite trustworthy, as the sample had been frozen a little on the bottle before the examination. The water was, however, well stirred in the glass cylinder, and was left alone for some time before being examined. (Note in journal).

[2] While the previous water-sample was being taken, the screw-stopper, closing the hole for insertion of the thermometer in the upper lid of the water-bottle, was lost in the sea, and the water-samples from 40 m. to 250 m. had to be taken with this hole open, on the 14th and 15th April. The specific gravities found on these dates may thus be a little too low, although the water-bottle proved to close very tightly.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C}$	Salinity.
	1894.	m.		° C.					‰
14	April 15	80	*S* 20	10·2	2649	2520	+ 55	1·02575	33·86
	[April 21] 80° 11′ N 133 36 E	100	—	10·5	2666	2542	—	1·02597	34·15
		120	—	10·8	2688	2568	—	1·02623	34·49
		140	—	7·7	2751	2590	—	1·02645	34·78
		160	—	7·9	2668	2510	—	[1·02565]	[33·72?]
		180	—	7·8[1]	2744	2585	—	1·02640	34·72
		200	—	7·6	2750	2588	—	1·02643	34·76
		250	*S* 20	7·8	2765	2606			
		—	—	8·4	2762	2610			
						2608	+ 54	1·02662	35·01
	April 21 [Apr. 23]	250[2]	*M* 7	12·10	2704	2603			
			—	12·18	2703	2604			
						2604	+ 55	1·02659	34·97
	April 23 [Apr. 24] 80° 28′ N 131 14 E	250	*M* 7	10·90	2742	2623	+ 55	1·02678	35·22
		300[3]	*M* 7	10·26	2743	2614			
			—	10·50	2743	2608	+ 70	1·02678	
			—	10·86	2733	2617			
			—	11·20	2737	2623	+ 40	1·02663	
			—	11·66	2728	2620			
			—	12·50	2709	2615			
			S 20	12·7	2708	2617			
						2616	+ 55	1·02671	35·12
		400	*M* 7	11·60	2735	2627			
			—	11·64	2732	2625			
						2626	+ 55	1·02681	35·26
		500	*M* 7	10·65	2746	2623	+ 55	1·02678	35·22
		600	*M* 7	10·38	2749	2622			
			—	10·50	2742	2617			
						2620	+ 55	1·02675	35·18

[1] In the journal, the record is 9·2° C., but this is probably a mistake for 8·2° C., which corrected gives 7·8° C.

[2] A new screw-stopper had now been made for the hole in the lid of the water-bottle.

[3] The first 5 determinations of this water-sample were made in a larger glass cylinder, while the last two determinations were made in the mended glass cylinder generally used.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1894.	m.		° C.					‰
14	April 24	800	*M* 7	11·02	2749	2632			
	[Apr. 25]		—	11·16	2748	2633			
	80° 30′ N								
	131 30 E					2633	+ 55	1·02688	35·35
		1000	*M* 7	11·52	2739	2629			
			—	11·56	2738	2629			
						2629	+ 55	1·02684	35·29
		1200	*M* 7	11·44	2733	2622			
			—	11·51	2727	2627			
						2625	+ 55	1·02680	35·24
	April 26	1400[1]	*M* 7	7·71	27975	2637	+ 69	1·02706	
	[Apr. 27]		—	7·80	2809	2649	+ 39	1·02688	
	80° 35′ N		—	7·85	2803	2644			
	131 34 E		—	7·88	2799	2640			
						2643	+ 54	1·02697	35·47
		1600[1]	*M* 7	7·99	2790	2833	+ 39	1·02672	
			—	7·93	2789	2631			
			—	7·96	2790	2632			
			—	8·28	2778	2624	+ 69	1·02693	
			—	8·28	2779	2626			
			—	8·39	2778	2626			
						2629	+ 54	1·02683	35·28
	April 25	1800	*M* 7	10·82	2748	2628			
	[April 26]		—	10·83	2748	2628			
						2628	+ 55	1·02683	35·28
		2200	*M* 7	10·75	2742	2621			
			—	10·77	2739	2618			
			—	10·79	2741	2621			
						2620	+ 55	1·02675	35·18
	April 26	2400	*M* 7	11·95	2738	2635			
	[April 26]		—	11·95	2737	2634			
			—	11·99	2737	2635			
						2635	+ 55	1·02690	35·37

[1] Water-samples were also taken from these two depths with Ekman's water-bottle, on April 24th, 1894. This bottle did not close tightly (see p. 141), and therefore the determinations of the specific gravity of the water-samples are of no value here: they are given on p. 141.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1894.	m.		° C.					‰
15	May 22	0·3	*M* 7	8·66	2370	2228	+ 57	1·02285	30·05
	[May 23] 81° 24′ N 125 0 E	10	—	6·87	2417	2255	—	1·02312	30·40
		20	—	6·61	2406	2241	—	1·02298	30·22
		40	—	7·06	2569	2405	+ 55	1·02460	32·35
	May 24]	60	—	10·19	2636	2508	—	1·02563	33·70
		80	—	9·79	2678	2544	—	1·02599	34·18
		100	—	10·01	2684	2553	—	1·02608	34·28
		120	—	9·36	2702	2561	—	1·02616	34·40
		160	—	9·71	2718	2582	—	1·02637	34·68
		200	—	9·29	2729	2588	—	1·02643	34·76
	May 23 [May 25] 81° 27′ N 124 0 E	300	—	9·12	2749	2605	—	1·02660	34·98
		400[1]	—	9·78	2746	2611	—	1·02666	35·06
		500[2]	—	9·74	2745	2609	—	1·02664	35·03
		600[1]	— —	9·67 9·74	2738[3] 2745	2601 2609	— —	[1·02656][3] 1·02664	 35·03
	May 24 81° 33′ N 123 2 E	700[2]	—	8·83	2755	2608	+ 54	1·02662	35·01
		1000[2]	— —	9·44 9·57	[2738] 2748	2598 2609	+ 55 —	[1·02653] 1·02664	[34·87] 35·03
		1400[2]	—	9·36	2756	2615	+ 54	1·02669	35·10
	May 25 [May 30] 81° 31′ N 123 2 E	1600[2]	—	9·08	2759	2614	—	1·02668	35·08
		2000[2]	—	10·64	2737	2614	+ 55	1·02669	35·10
		2200[2]	— —	10·53 10·60	2749 2749	2625 2626			
						2626	+ 55	1·02681	35·26

[1] These water-samples were taken only from the central tube of the water-bottle. The glass bottles were well rinsed with water from the outer chambers, before the sample was taken.

[2] The glass bottles were well rinsed with water from the outer chambers of the water-bottle, before the samples were taken, which was done chiefly from the central tube, but some portion of each sample also from the outer chambers.

[3] A drop of water adhered to the stem of the hydrometer during the observation.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
	1894.	m.		° C.					‰
16	May 26	2400	—	10·72	2649	2528	+ 70	1·02598	
	81° 31′ N		—	10·78	2680	2560	+ 40	1·02600	
	123 0 E		—	10·86	2678	2559			
			—	11·00	2670	2553			
			—	11·10	2660	2545			
			—	11·22	2651	2537			
						2547	+ 55	[1·02602]	[34·19][1]
	June 26	0·20	*M* 6	7·47	0448	0345			
	[June 27]			7·62	0446	0343			
	81° 37′ N					0344	+ 40	1·00384	5·05
	121 6 E								
		5	*M* 6	7·97	2360	2209			
			—	8·04	2362	2213			
			—	8·14	2359	2211			
			—	8·20	2358	2210			
			—			2211	+ 57	1·02268	29·82
	June 22	10	*S* 20	14·3	2262	2201	+ 72	1·02273	
	[June 22]		—	14·2	2265	2202			
	81° 46′ N		—	14·1	2265	2201			
	121 40 E		—	14·0	2267	2201			
			—	12·9	2295	2210			
			—	12·8	2299	2213	+ 42	1·02254	
			—	12·7	2289	2201			
			—	12·5	2303[2]	2212			
						2205	+ 57	1·02262	29·74
		20	*M* 6	7·02	2379	2218			
			—	7·37	2378	2222			
			—	7·56	2369	2215	+ 72	1·02287	
			—	7·77	2374	2222			
			—	8·02	2373	2223	+ 42	1·02265	
						2220	+ 57	1·02277	29·93
		30	*M* 6	10·10	2350	2225			
			—	10·17	2350	2225			
			—	10·22	2349	2225			
			—	10·29	2355[3]	2232			
			—	10·33	2354	2232			
			—	10·03	2345[4]	2219	+ 72	1·02291	

[1] This result is evidently worthless. The water-bottle has probably been closed in some higher strata, perhaps about 100 m. deep.
[2] Hydrometer wiped.
[3] Stem wiped.
[4] An hour later.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction	$S\frac{17{\cdot}5^\circ\,C.}{15{\cdot}5^\circ\,C.}$	Salinity.
16	1894.	m.		° C.					‰
	June 22	30	*M* 6	10·19	2358[1]	2234			
	[June 22]		—	10·31	2356	2233			
	81° 46′ N		*Gr.*	10·58	2355[2]	2236	+ 42	1·02278	
	121 40 E		—	10·65	2353	2235			
			—	10·79	2342	2226			
			—	10·89	2339[3]	2225			
			—	10·94	2348[3]	2234			
			—	11·14	2340	2227			
			—	11·15	2341	2229			
			—	11·33	2343[4]	2234			
			—	11·34	2344	2236			
			—	11·49	2340[3]	2234			
			—	11·58	2338	2233			
			—	11·59	2340[3]	2235			
			—	11·63	2339	2235			
						2231	+ 57	1·02288	30·08
			Gr.	11·83	*2400[5]	2297			
			—	11·92	*2404	2303			
			—	11·93	*2405	2304			
			—	11·93	*2415[3]	2314			
			—	12·03	*2430	2330			
			—	12·13	*2428	2330			
			—	12·13	*2429	2331			
			—	12·18	*2422	2325			
			—	12·23	*2424	2328			
			—	12·23	*2428	2331			
			—	12·32	*2420	2325			
			—	12·33	*2421[3]	2326			
			—	12·32	*2422[3]	2327			
			—	12·33	*2427[3]	2332			
			—	12·34	*2426[6]	2331			
			—	12·37	*2428	2334			
			—	12·34	*2426	2331			
			—	12·34	*2422	2327			
						2324	— 27	1·02297	30·21

[1] Stem wiped.

[2] The succeeding 13 observations were made in a larger glass cylinder with the thermometer Grave hanging continuously in the water; while the previous 8 observations were made as usual in the mended cylinder, where the thermometer Müller No. 6 was immersed and removed between each observation.

[3] Hydrometer wiped.

[4] Stem wiped with linen handkerchief, as the wash-leather previously used was rather moist.

[5] The succeeding 18 observations with the hydrometer Küchler No. 4 were taken in the large glass cylinder with the thermometer Grave hanging continuously in the water.

[6] Hydrometer wiped with handkerchief instead of wash-leather.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
16	1894.	m.		° C.					‰
	[June 23]	40	*M* 6	8·04	2560	2407			
			—	8·17	2561[1]	2409			
			—	8·25	2559	2409			
						2408	+ 55	1·02463	32·39
		50	*M* 6	8·12	2636	2481			
			—	8·18	2638	2474	+ 70	1·02544	
			—	8·34	2648[2]	2496	+ 40	1·02536	
			—	8·36	2640	2489			
			—	8·48	2643	2492			
						2486	+ 55	1·02541	33·41
		60	*M* 6	8·22	2672	2518			
			—	8·20	2669[2]	2515			
			—	8·35	2668	2515			
						2516	+ 55	1·02571	33·81
	June 23	80	*M* 6	6·24	2709	2531			
	[June 23]		—	6·43	2708	2532			
	81° 42′ N		—	6·64	2708	2535			
	121 30 E		—	6·77	2709	2537			
						2534	+ 55	1·02589	34·05
		100	*M* 6	11·21	2686	2572			
			—	11·10	2692	2577			
			—	11·13	2691	2576			
						2575	+ 55	1·02630	34·58
		120[3]	*M* 6	6·26	2735	2557	+ 70	1·02627	
			—	6·34	2739	2562			
			—	6·66	2742	2569			
			—	6·64	2738	2564			
			—	6·67	2740	2567			
			—	5·99	2739	2558			
			—	6·17	2749	2570			
			—	6·27	2749	2571			
			—	6·36	2748	2571			
			—	6·83	2746	2574			
			—	6·92	2745	2575	+ 40	1·02615	
						2567	+ 55	1·02622	34·47

[1] Stem wiped.
[2] Hydrometer wiped.
[3] The determinations of this water-sample were made in the large glass cylinder.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17.5°\,C.}{17.5°\,C.}$	Salinity.
	1894.	m.		° C.					‰
16	June 25	140	*M* 6	5·26	2762	2576			
	[June 25]		—	5·61	2762	2579			
	81° 39′ N		—	5·63	2762[1]	2579			
	121 0 E		—	5·91	2757	2576			
			—	6·17	2756	2577			
						2577	+ 54	1·02631	34·60
	June 25	160	*M* 6	5·73	2768	2586			
	[June 27]		—	5·83	2769	2586			
	81° 37′ N		—	6·01	2762[1]	2582			
	121 6 E		—	6·11	2766	2587			
			—	6·35	2763	2586			
						2586	+ 54	1·02640	34·72
		180	*M* 6	7·47	2751	2588			
			—	7·62	2751	2589			
			—	7·70	2749	2588			
			—	7·57	2756[1]	2593			
			—	7·66	2757	2595			
			—	7·80	2756	2596			
			—	7·90	2755	2596			
						2592	+ 54	1·02646	34·79
		200	*M* 6	7·80	2778	2618	+ 39	1·02655	
			—	7·56	2758	2595	+ 69	1·02662	
			—	7·92	2765	2606			
			—	7·97	2765	2607			
			—	8·09	2764	2607			
			—	7·82	2763[1]	2603			
			—	7·95	2765	2606			
			—	8·07	2765	2608			
			—	8·16	2763	2607			
						2606	+ 54	1·02660	34·98
		225	*M* 6	7·36	2760	2595	+ 69	1·02664	
			—	7·57	2769	2606			
			—	7·67	2768	2606			
			—	7·62	2758[1]	2596			
			—	7·72	2766	2605			
			—	7·82	2766	2606			
			—	7·88	2770	2611	+ 39	1·02650	
			—	7·97	2765	2607			
						2604	+ 54	1·02658	34·95

[1] The succeeding observations of this water-sample were made in the large glass cylinder.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
	1894.	m.		° C.					‰
16	June 25	250	*M* 6	7·67	2785	2623			
	[June 27]		—	7·84	2783	2623			
	81° 37′ N		—	7·82	2783[1]	2623			
	121 6 E		—	7·93	2784	2625			
			—	8·02	2782	2624			
						2624	+ 54	1·02678	35·22
	June 25	275	*M* 6	7·12	2790[1]	2622			
	[June 25]		—	7·22	2789	2622			
	81° 39′ N		—	7·29	2788	2622			
	121 0 E		—	7·52	2796[2]	2632			
			—	7·68	2792	2630			
			—	7·85	2785[2]	2625			
			—	8·07	2790[3]	2632			
			—	8·17	2785	2629			
			—	8·71	2771[4]	2622			
			—	8·82	2771	2623			
			—	8·90	2768	2621	+ 69	1·02688	
			—	8·95	2769	2623			
			—	9·06	2778[3]	2633	+ 39	1·02670	
			—	9·30	2769[4]	2627			
			—	9·40	2768	2627			
			—	9·50	2764[5]	2624			
			—	9·60	2765[5]	2627			
			—	9·83	2761[4]	2626			
			—	9·87	2759	2625			
						2626	+ 54	1·02680	35·24
	[June 26]	300	*M* 6	7·02	2787	2618			
			—	7·17	2786	2618			
			—	7·27	2786	2619			
						2618	+ 54	1·02672	35·14
16 a	June 26	310	*M* 6	7·10	2780	2611	+ 69	1·02680	
	[June 27]		—	7·22	2779	2612			
	81° 37′ N		—	7·37	2781[2]	2615			
	121 6 E		—	7·42	2792	2627			
			—	7·52	2793	2629	+ 39	1·02668	
			—	7·56	2788	2625			
						2620	+ 54	1·02674	35·16

[1] The succeeding observations of this water-sample are made in the large glass cylinder.
[2] Hydrometer wiped.
[3] Stem wiped.
[4] After being left for some time undisturbed.
[5] Hydrometer dipped in to wet the stem.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1894.	m.		° C.					‰
16	June 25	325	*M* 6	6·94	2792	2621			
	[June 26]		—	7·01	2792	2623			
	81° 39′ N		—	7·12	2794[1]	2626			
	121 0 E		—	7·22	2789	2622			
						2623	+ 54	1·02677	35·20
	June 26	350	*M* 6	3·58	2825	2625			
	[June 26]		—	4·00	2824	2627			
	81° 37′ N		—	4·95	2802	2613			
	121 6 E		—	5·30	2795	2609	+ 69	1·02678	
			—	5·96	2812[2]	2632			
			—	6·11	2812	2633	+ 39	1·02672	
			—	6·26	2809	2632			
						2624	+ 54	1·02678	35·22
		375	*M* 6	4·90	2806	2616			
			—	5·30	2803[1]	2617			
			—	5·61	2802	2618			
			—	5·81	2801	2619			
						2618	+ 54	1·02672	35·14
		400	*M* 6	4·60	2803	2610	+ 69	1·02679	
			—	6·57	2799[3]	2624			
			—	6·67	2798	2624			
			—	6·82	2789[1]	2627	+ 39	1·02666	
						2621	+ 54	1·02675	35·18
		425	*M* 6	6·26	2798	2620			
			—	6·43	2799	2623			
			—	6·87	2797	2626			
			—	6·98	2795	2625			
						2624	+ 54	1·02678	35·22
		450	*M* 6	6·62	2796	2622	+ 69	1·02691	
			—	6.72	2788	2625			
			—	6·94	2809[2]	2639	+ 39	1·02678	
			—	7·02	2792	2623			
						2627	+ 54	1·02681	35·26
		500	*M* 6	5·56	2808	2624			
			—	5·66	2807	2624			
			—	5·86	2814[4]	2633			
			—	5·99	2813	2633			
			—	6·10	2810	2631			
						2629	+ 54	1·02683	35·28

[1] Stem wiped.
[2] Stem wiped, and after being left for some time undisturbed.
[3] The succeeding observations were made after dinner.
[4] Hydrometer wiped.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
	1894.	m.		° C.					‰.
16	June 26	550	*M* 6	5·56	2811	2627			
	[June 26]		—	5·61	2810	2627			
	81° 37′ N		—	5·77	2803	2621			
	121 6 E					2625	+ 54	1·02679	35·23
		600	*M* 6	6·87	2804	2632			
			—	7·00	2808[1]	2638			
			—	7·04	2797	2628			
						2633	+ 54	1·02687	35·33
		700	*M* 6	6·97	2790	2620			
			—	7·17	2800[2]	2632			
			—	7·25	2788	2621			
			—	7·47	2785	2620			
						2623	+ 54	1·02677	35·20
	June 27	800	*M* 6	7·16	2780	2612			
	[June 27]		—	7·34	2776	2610	+ 69	1·02679	
	81° 36′ N		—	7·47	2779	2614			
	121 12 E		—	7·67	2781[1]	2619			
			—	7·80	2780	2620	+ 39	1·02659	
						2615	+ 54	1·02669	35·10
		1000	*M* 6	7·07	2789	2620	+ 39	1·02659	
			—	7·24	2786	2619			
			—	7·52	2778[1]	2615			
			—	7·72	2770[3]	2608	+ 69	1·02677	
						2616	+ 54	1·02670	35·11
		1200	*M* 6	5·15	2793	2606			
			—	5·96	2790	2609			
			—	6·21	2791[1]	2613			
			—	6·56	2779	2604	+ 69	1·02673	
			—	6·77	2786	2613			
			—	7·08	2783	2614			
			—	7·20	2782	2615	+ 39	1·02654	
						2611	+ 54	1·02665	35·04

[1] Stem wiped.
[2] Hydrometer wiped.
[3] Hydrometer dipped in to wet the stem.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C}{15{\cdot}5^\circ\,C.}$	Salinity.
	1894.	m.		° C.					‰
16	June 27	1600	*M* 6	8·22	2762	2607	+ 69	1·02676	
	[June 27]		—	8·36	2768	2615			
	81° 36′ N		—	8·42	2764	2612			
	121 12 E		—	8·58	2768[1]	2618			
			—	8·60	2767	2617			
			—	8·71	2771	2622			
			—	8·78	2770	2622	+ 39	1·02661	
						2616	+ 54	1·02670	35·11
17	July 11	0·05[2]	*M* 7	8·38	*0186	0100			
	[July 12 & 13]		—	8·65	*0177	0092			
	81° 19′ N		—	8·73	*0176	0091			
	124 38 E		—	8·78	*0179	0094			
						0094	?	1·00094	1·24
		0·12[3]	*M* 7	9·18	*0187	0103			
			—	9·38	*0192	0109			
			—	9·69	*0186	0103			
			—	10·49	*0184	0107			
						0106	?	1·00106	1·36
		1	*M* 7	8·48	*0176	0090			
			—	8·53	*0178	0092			
			—	8·55	*0177	0091			
						0091	?	1·00091	1·20
		2	*M* 7	8·48	*0256	0169			
			—	8·63	*0255	0169			
			—	8·63	*0255	0169			
						0169	?	1·00169	2·22
		3	*M* 7	9·67	2292	2162			
			—	9·65	2290	2159			
			—	9·71	2288	2158			
			—	9·73	2288	2159			
						2160	+ 57	1·02217	29·16

[1] Stem wiped.

[2] Taken with a glass bottle, the opening of which was at a depth of about 5 cm. below the water-surface while it was being filled.

[3] The water-sample was taken with Pettersson's water-bottle. The lid was just on the water-surface when the bottle was closed.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
	1894.	m.		° C.					‰
17	July 11	5	*M* 7	8·85	*2454	2311	— 42	1·02269 ?	
	[July 12 & 13]		—	9·05	*2422	2280	— 27	53	
	81° 19′ N		—	9·23	*2420	2281	—	54	
	124 38 E		—	9·28	*2419	2281	—	54	
			—	9·38	*2418	2281	—	54	
			—	10·34	2323	2200	+ 57	57	
			—	10·44	2318	2196	—	53	
			—	10·55	2317	2197	—	54	
			—	10·75	2315	2198	—	55	
								1·02254	29·64
		10	*M* 7	9·74	2323	2192			
			—	9·84	2319	2189			
			—	9·84	2318	2188			
			—	10·05	2320	2193			
			—	10·12	2320	2194			
						2191	+ 57	1·02248	29·56
19	Oct. 18	5	*M* 6	10·64	2347	2229	+ 42	1·02271	
	[Oct. 20]		—	11·12	2330	2218	+ 57	75	
	81° 48′ N		—	11·25	2326	2216	—	73	
	115 30 E		—	11·33	2329	2220	—	77	
			—	11·45	2328	2220	—	77	
			—	11·97	*2400	2300	— 27	73	
			—	11·96	*2401	2299	—	72	
			—	12·00	*2400	2300	—	73	
			—	12·02	*2402	2303	—	76	
			—	12·08	*2401	2303	—	76	
								1·02274	29·90
	Oct. 17	50	*S* 20	15·1	2551	2503			
	[Oct. 18]		—	15·2	2555	2509			
	81° 44′ N		—	15·2	2554	2509			
	115 40 E		—	15·3	2553	2509			
						2508	+ 55	1·02563	33·70
		150	*S* 20	13·8	2670	2599	+ 40	1·02639	
			—	14·1	2659	2593			
			—	14·4	2654	2594			
			—	14·5	2650	2591			
			—	14·6	2639	2582	+ 70	1·02652	
			—	14·7	2641	2586			
			—	14·8	2641	2587			
						2591	+ 55	1·02646	34·79

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydro-meter.	Reading referred to 17·5° C.	Correc-tion.	$S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1894.	m.		° C.					‰
19	Oct. 17	200	*S* 20	14·0	2688	2621			
	[Oct. 18]		—	14·1	2687	2622			
	81° 44′ N		—	14·3	2683	2621			
	115 40 E		—	14·5	2680	2622			
						2622	+ 55	1·02677	35·20
	[Oct. 19]	250	*M* 6	8·27	2769	2614			
			—	8·34	2769	2615			
			—	8·42	2768	2615			
						2615	+ 54	1·02669	35·10
		300	*M* 6	8·47	2779	2627			
			—	8·48	2778	2626			
			—	8·52	2774	2622			
			—	8·56	2770	2619			
			—	8·59	2769	2618			
						2622	+ 54	1·02676	35·19
	Oct. 18	350	*M* 6	8·23	2780	2625			
	[Oct. 19]		—	8·26	2779	2625			
	81° 48′ N		—	8·32	2779	2625			
	115 30 E		—	8·34	2778	2624			
						2625	+ 54	1·02679	35·23
		400	*M* 6	8·63	2784	2634			
			—	8·64	2783	2633			
			—	8·70	2779	2630			
			—	8·70	2788	2639			
						2632	+ 54	1·02686	35·22
		450	*M* 6	8·37	2804	2650	+ 39	1·02689	
			—	8·47	2795	2642			
			—	8·75	2790	2641			
			—	8·83	2783	2635			
			—	8·95	2878	2631			
			—	9·78	2768	2633			
			—	9·80	2761	2625	+ 69	1·02694	
			—	9·88	2761	2626			
						2635	+ 54	1·02689	35·36
		500	*M* 6	9·18	2777	2633			
			—	9·30	2769	2626			
			—	9·38	2769	2628			
			—	9·47	2768	2628			
						2629	+ 54	1·02683	35·28

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
	1894.	m.		° C.					‰
19	Oct. 18	600	*M* 6	9·29	2760	2617			
	[Oct. 19]		—	9·45	2756	2616			
	81° 48′ N		—	9·66	2753	2615			
	115 30 E		—	9·80	2755	2619			
						2617	+ 54	1·02671	35·12
	[Oct. 20]	700	*M* 6	7·28	2790	2624			
			—	7·59	2792	2629			
			—	7·77	2788	2626			
			—	8·07	2785	2628			
			—	8·12	2779	2623			
			—	8·42	2779	2626			
						2626	+ 54	1·02680	35·24
		800	*M* 6	9·18	2776	2632	+ 39	1·02671	
			—	9·46	2763	2623			
			—	9·55	2760	2621	+ 69	1·02690	
			—	9·79	2760	2624			
			—	9·96	2759	2626			
						2625	+ 54	1·02679	35·23
	Oct. 19	800	*M* 6	9·43	2760	2619	+ 69	1·02688	
	[Oct. 20]		—	9·73	2767	2631			
	81° 55′ N		—	9·83	2767	2632	+ 39	1·02671	
	115 8 E		—	9·97	2765	2632			
						2629	+ 54	1·02683	36·28
	Oct. 20	1500	*M* 6	10·92	2751	2632			
	[Oct. 20]		—	11·13	2741	2625			
	82° 0′ N		—	11·14	2740	2624			
	114 51 E		—	11·25	2739	2625			
			—	11·36	2737	2625			
						2626	+ 54	1·02680	35·24
		2000[1]	*M* 6	10·34	2480	2355			
			—	11·20	2459	2346			
			—	11·55	2449	2337			
						2346	+ 54	[1·02400][1]	

[1] This water-sample is worthless, as the stop-cock of the water-bottle had been left open when it went down.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydro-meter.	Reading referred to 17·5° C.	Correc-tion.	$S\frac{17{\cdot}5^{\circ}\,C.}{17{\cdot}5^{\circ}\,C.}$	Salinity.
	Oct. 27	m.		° C.					‰
19	[Nov. 12] 82° 4′ N 114 35 E	2500	*M* 6	11·25	2754	2640			
			—	11·55	2742	2633			
			—	11·80	2740	2634			
			—	12·05	2739	2637			
			—	12·25	2737	2638			
			S 20	12·32	2737	2640			
						2637	+ 54	1·02691	35·39
	Oct. 29, [Nov. 12] 82° 11′ N 113 13 E	3000	*S* 20	13·9	2718	2649	+ 35	1·02684	
			—	14·3	2688	2626			
			—	14·3	2688	2626			
			—	14·5	2688	2630			
			—	14·6	2678	2621			
			—	14·6	2680	2623			
			—	14·9	2678[1]	2626			
			—	15·1	2664	2616	+ 69	1·02685	
			—	15·4	2666	2624			
			—	15·4	2671	2629			
			—	15·7	2670	2634			
			—	15·7	2668	2632			
						2628	+ 54	1·02682	35·27
20	Nov. 3 [Nov. 10] 82° 6′ N 111 30 E	0·5	*M* 6	8·27	*0443	0351			
			—	9·24	*0426	0338			
			—	10·34	*0422	0340			
			—	11·00	*0418	0341			
			—	11·35	*0417	0343			
						0343	?	1·00343	4·52
		2	*S* 20	16·4	*2338	2316			
			—	16·5	*2338	2318			
			—	16·6	*2337	2319			
			—	16·9	*2328	2316			
			—	17·3	*2324	2321			
						2318	— 27	1·02291	30·12
		10	*S* 20	16·1	*2341	2313			
			—	16·3	*2339	2315			
			—	16·5	*2338	2318			
			—	16·7	*2336	2210			
						2317	— 27	1·02290	30·11

[1] Hydrometer wiped dry.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
	1894.	m.		° C.					‰
20	Nov. 3	25	*S* 20	17·5	*2339	2339			
	[Nov. 10]		—	18·1	*2320	2333			
	82° 6′ N		—	18·1	*2310	2323			
	111 30 E		—	18·4	*2305	2324			
			—	18·6	*2298	2322			
			—	18·6	*2295	2319			
			—	18·3	*2304	2321			
			—	18·4	*2298	2317			
						2325	— 27	1·02298	30·22
		50	*S* 20	14·2	2581	2519			
			—	14·2	2580	2518			
			—	14·3	2578	2517			
			—	14·4	2572	2513			
			—	14·6	2571	2515			
						2516	+ 55	1·02571	33·81
	Nov. 2	100	*S* 20	11·8	2670	2565			
	[Nov. 3]		*M* 6	12·20	2669	2570			
	82° 6′ N		*S* 20	12·4	2658	2562			
	111 30 E		—	12·6	2663	2570			
			—	12·8	2654	2565			
						2566	+ 55	1·02621	34·74
		200	*S* 20	13·9	2685	2616			
			—	14·1	2686	2621			
			—	14·2	2684	2620			
			—	14·3	2680	2618			
						2619	+ 55	1·02674	35·16
	[Nov. 2]	310	*S* 20	14·1	2672	2604	+ 70	1·02674	
			—	16·3	2639	2615			
			—	16·6	2628	2610			
			—	17·2	2632	2627	+ 40	1·02667	
			—	17·2	2618	2613			
			—	17·4	2618	2617			
						2614	+ 55	1·02669	35·10
	[Nov. 3]	350	*S* 20	15·3	2662	2618			
			—	15·3	2668	2624			
			—	15·4	2663	2621			
			—	15·4	2660	2618			
						2620	+ 55	1·02675	35·18

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydro-meter.	Reading referred to 17·5° C.	Correc-tion.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
		m.		° C.					
20	1894.	400	*M* 6	11·30	2722	2609			
	Nov. 3		—	11·55	2727	2617			
	[Nov. 12]		—	11·75	2719	2612			
			—	11·77	2719	2613			
						2613	+ 55	1·02668	35·08
		600	*M* 6	10·06	2750	2619			
			—	10·54	2748	2623			
			—	10·61	2746	2622			
			—	10·90	2746	2627			
						2623	+ 54	1·02677	35·20
		700	*M* 6	9·83	2758	2623	+ 40	1·02663	
			—	10·28	2745	2616			
			—	11·70	2729	2623			
			—	12·00	2723	2622			
			—	12·20	2720	2621			
			S 20	12·5	2709	2615			
			—	13·0	2690	2604	+ 70	1·02674	
			—	13·1	2689	2605			
			—	13·3	2690	2609			
						2615	+ 55	1·02670	35·11
		1000	*M* 6	9·13	2765	2620			
			—	9·58	2762	2624			
			—	9·68	2760	2632			
			—	9·88	2756	2622			
			—	10·13	2758	2627			
						2623	+ 54	1·02677	35·20
21	1895.								
	Apr. 6	0	Ca.	14·4	2357	2297			
	[Apr. 16]		—	14·7	2355	2300			
	84° 18′ N		—	14·9	2353	2301			
	96 40 E		—	14·95	2352	2301			
			—	15·2	2350	2304			
						2300	+ 57	1·02357	31·00
		5	Ca.	13·9	2378	2309			
			—	14·2	2374	2311			
			—	13·35	2372	2311			
			—	14·85	2367	2314			
			—	14·95	2365	2314			
			—	15·2	2360	2314			
						2312	+ 57	1·02369	31·15

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1895.	m.		° C.					‰
22 a	May 13 [1]	0	*Ca.*	10·67	2454	2335	+ 42	1·02377	
	[May 13]		—	10·87	2448	2332			
	84° 39′ N		—	11·12	2441	2328			
	88 30 E		—	11·17	2440	2328			
			—	11·97	2427	2326			
			—	12·12	2421	2322	+ 72	1·02394	
						2329	+ 57	1·02386	31·37
	May 14	10	*Ca.*	8·67	2470	2324			
	84° 39′ N		—	8·87	2466	2322			
	88 15 E		—	9·17	2463	2322			
			—	9·42	2461	2324			
			—	9·97	2453	2323			
						2323	+ 57	1·02380	31·30
		250	*Ca.*	11·87	2722	2617			
			—	12·32	2612	2615			
			—	12·47	2710	2615			
			—	12·92	2703	2616			
			—	13·07	2700	2615			
						2616	+ 55	1·02671	35·12
		300	*Ca.*	10·67	2740	2617			
			—	10·97	2738	2620			
			—	11·37	2730	2618			
			—	11·47	2729	2618			
			—	11·87	2723	2618			
						2618	+ 55	1·02673	35·15
22	May 25	0	*Ca.*	10·27	2505	2379			
	[May 25]		—	10·42	2503	2379			
	84° 40′ N		—	10·77	2500	2381			
	82 15 E		—	10·87	2499	2382			
			—	11·02	2498	2383			
						2381	+ 56	1·02437	32·05
	May 24	20	*Ca.*	11·07	2522	2408			
	[May 25]		—	11·57	2519	2412			
	84° 41′ N		—	11·77	2518	2414			
	82 24 E		—	12·17	2514	2414			
			—	12·32	2512	2414			
						2412	+ 56	1·02468	32·45

[1] After May 13th, all water-samples were taken with Blessing's water-bottle. The water-samples and the temperatures of the water-strata were not taken simultaneously before July 25th, 1895.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydro-meter.	Reading referred to 17·5° C.	Correc-tion.	$S\frac{17{\cdot}5^\circ C}{17{\cdot}5^\circ C.}$	Salinity.
22	1895.	m.		° C.					‰
	May 24	40	*Ca.*	10·62	2590	2469			
	[May 25]		—	10·82	2588	2472			
	84° 41 N		—	11·22	2585	2473			
	82 24 E		—	11·47	2581	2472			
			—	11·72	2579	2474			
						2472	+ 55	1·02527	32·23
60			*Ca.*	9·87	2649	2516	+ 70	1·02586	
			—	10·42	2645	2519			
			—	10·77	2641	2520			
			—	11·27	2640	2526			
			—	11·42	2639	2528			
			—	11·57	2638	2529	+ 40	1·02569	
						2523	+ 55	1·02578	33·90
80			*Ca.*	9·62	2681	2543			
			—	9·67	2679	2542			
			—	10·07	2673	2541			
			—	10·17	2671	2541			
			—	10·47	2669	2543			
						2542	+ 55	1·02597	34·15
100			*Ca.*	8·87	2697	2549			
			—	9·12	2695	2550			
			—	9·37	2692	2550			
			—	9·47	2690	2550			
			—	9·77	2688	2552			
						2550	+ 55	1·02605	34·26
150			*Ca.*	8·57	2732	2581			
			—	8·87	2729	2582			
			—	9·17	2724	2580			
			—	9·52	2720	2581			
			—	9·77	2718	2582			
						2581	+ 55	1·02636	34·66
200			*Ca.*	7·57	2757	2595			
			—	7·87	2755	2598			
			—	8·27	2752	2598			
			—	8·37	2751	2598			
			—	8·62	2749	2599			
						2598	+ 54	1·02652	34·67

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
22	1895.	m.		° C.					‰
	[May 24]	250	*Ca.*	10·57	2730	2606			
			—	10·87	2729	2609			
			—	11·17	2727	2612			
			—	11·52	2725	2617			
			—	12·07	2720	2619			
						2613	+ 55	1·02668	35·08
		300	*Ca.*	8·87	2756	2609			
			—	9·47	2752	2612			
			—	9·87	2749	2614			
			—	10·37	2746	2619			
			—	10·67	2743	2620			
			—	10·82	2741	2620			
						2616	+ 55	1·02671	35·12
		350	*Ca.*	10·17	2750	2620			
			—	10·47	2748	2622			
			—	10·67	2745	2622			
			—	10·97	2742	2624			
			—	11·37	2738	2626			
						2623	+ 55	1·02678	35·22
		400	*Ca.*	7·82	2777	2617			
			—	8·37	2770	2617			
			—	8·62	2768	2618			
			—	8·87	2767	2620			
			—	9·17	2766	2622			
			—	9·37	2765	2623			
						2620	+ 54	1·02674	35·16
		450	*Ca.*	8·52	2769	2618			
			—	8·87	2765	2618			
			—	9.07	2764	2619			
			—	9·37	2762	2620			
			—	9·72	2760	2623			
						2620	+ 54	1·02674	35·16
		500	*Ca.*	8·07	2773	2616			
			—	8·47	2769	2617			
			—	8·57	2768	2617			
			—	8·87	2766	2619			
			—	9·22	2765	2621			
						2618	+ 54	1·02672	35.14

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
22	1895.	m.		° C.					‰
	[May 24]	550	*Ca.*	4·77	2819	2628			
			—	5·57	2797	2614			
			—	5·77	2799	2618			
			—	6·07	2797	2618			
			—	6·42	2796	2620			
			—	7·37	2785	2620			
			—	7·77	2782	2622			
			—	7·87	2781	2622			
						2620	+ 54	1·02674	35·16
May 22		600	*Ca.*	10·37	2747	2620			
[May 22]			—	10·37	2749	2622			
84° 40′ N			—	10·47	2748	2622			
83 51 E			—	10·67	2747	2624			
			—	11·52	2738	2628			
			—	11·67	2737	2629			
						2624	+ 55	1·02679	35·23
		650	*Ca.*	10·87	2741	2721			
			—	11·27	2737	2623			
			—	11·67	2736	2628			
			—	11·87	2734	2630			
			—	12·07	2731	2630			
						2626	+ 55	1·02681	35·26
		700	*Ca.*	10·27	2747	2618			
			—	10·77	2742	2621			
			—	11·17	2740	2625			
			—	11·47	2739	2628			
			—	11·67	2736	2629			
						2624	+ 55	1·02679	35·23
		750	*Ca.*	6·92	2792	2621			
			—	7·32	2788	2622			
			—	7·87	2779	2619			
			—	8·27	2776	2621			
			—	8·67	2772	2622			
						2621	+ 54	1·02675	35·18
		800	*Ca.*	5·07	2816	2628			
			—	5·87	2811	2630			
			—	6·17	2809	2630			
			—	6·67	2805	2631			
			—	7·57	2798	2635			
						2631	+ 54	1·02685	35·31

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
22	1895.	m.		° C.					‰
	May 24	850	*Ca.*	8·87	2768	2621			
	[May 24]		—	9·07	2764	2619			
	84° 41′ N		—	9·32	2762	2620			
	82 24 E		—	9·42	2761	2620			
			—	9·82	2757	2622			
			—	9·87	2756	2622			
						2621	+ 54	1·02675	35·18
		900	*Ca.*	10·47	2741	2615			
			—	10·87	2733	2613			
			—	11·07	2732	2615			
			—	11·27	2731	2617			
			—	11·52	2728	2618			
						2616	+ 55	1·02671	35·12
		1000	*Ca.*	12·72	2709	2618			
			—	12·82	2707	2618			
			—	13·02	2706	2620			
			—	13·17	2703	2620			
			—	13·32	2701	2621			
			—	13·37	2700	2621			
						2620	+ 55	1·02675	35·18
	May 25	1100	*Ca.*	10·37	2747	2620			
	[May 25]		—	11·17	2740	2625			
	84° 40′ N		—	11·37	2738	2626			
	82 15 E		—	11·67	2733	2625			
			—	11·82	2731	2626			
						2624	+ 55	1·02679	35·23
		1200	*Ca.*	10·82	2746	2625			
			—	11·27	2743	2629			
			—	11·67	2732	2624			
			—	11·77	2730	2624			
			—	11·87	2729	2624			
						2625	+ 55	1·02680	35·24
	July 31[1]	0	*Ca.*	14·32	2411	2350			
	[Aug. 6]		—	14·57	2407	2350			
	84° 28′ N		—	14·77	2405	2351			
	75 35 E		—	15·27	2399	2354			
			—	15·62	2390	2352			
						2351	+ 57	1·02408	31·66

[1] After July 25th, 1895, the water-temperatures *in situ* and the water-samples were taken simultaneously as previous to May, 1895, the thermometer and water-bottle being attached to the same sounding-line.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydro-meter.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
	1895.	m.		° C.					‰
23	July 31	20	*Ca.*	14·37	2463	2403			
	[Aug. 6]		—	14·52	2461	2403			
	84° 28′ N		—	14·87	2452	2400			
	75 35 E		—	15·02	2449	2399			
			—	15·27	2447	2402			
						2401	+56	1·02457	32·31
40			*Ca.*	15·02	2532	2482			
			—	15·22	2530	2484			
			—	15·67	2526	2489			
			—	16·37	2519	2496			
			—	16·57	2515	2496			
						2489	+ 56	1·02545	33·47
60			*Ca.*	16·77	2529	2514			
			—	16·97	2527	2516			
			—	17·37	2520	2517			
			—	17·77	2515	2521			
			—	17·92	2512	2521			
						2518	+ 56	1·02574	33·85
80			*Ca.*	15·87	2574	2541			
			—	16·47	2566	2545			
			—	16·67	2562	2545			
			—	16·87	2558	2545			
			—	17·02	2555	2545			
						2544	+ 55	1·02599	34·18
100			*Ca.*	17·87	2543	2551			
			—	18·07	2541	2553			
			—	18·47	2538	2558			
			—	18·77	2535	2562			
			—	18·97	2530	2561			
						2557	+ 56	1·02613	34·36
120			*Ca.*	15·12	2610	2562			
			—	15·37	2606	2563			
			—	15·87	2598	2565			
			—	16·07	2595	2566			
			—	16·17	2593	2566			
						2564	+ 55	1·02619	34·44

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17·5°\,C.}{17·5°\,C.}$	Salinity.
	1895.	m.		° C.					‰
23	July 31	140	*Ca.*	15·87	2596	2563			
	[Aug. 6]		—	16·07	2591	2562			
	84° 28′ N		—	16·57	2587	2568			
	75 35 E		—	17·07	2579	2570			
			—	17·37	2571	2568			
						2566	+ 55	1·02621	34·47
	July 29	160	*Ca.*	16·07	2615	2586	+ 70	1·02656	
	[July 29]		—	16·27	2612	2587			
	84° 32′ N		—	16·57	2610	2591			
	74 17 E		—	16·87	2605	2592			
			—	17·47	2602	2602	+ 40	1·02642	
						2592	+ 55	1·02647	34·81
		180	*Ca.*	17·85	2580	2588			
			—	18·10	2578	2591			
			—	18·55	2573	2595			
			—	18·75	2571	2598			
			—	18·85	2570	2599			
						2594	+ 55	1·02649	34·83
	[July 30]	200	*Ca.*	13·75	2672	2600			
			—	14·15	2669	2604			
			—	14·60	2664	2607			
			—	14·85	2660	2607			
			—	15·10	2656	2608			
						2605	+ 55	1·02660	34·98
		250	*Ca.*	14·35	2679	2618			
			—	14·65	2674	2617			
			—	14·85	2671	2618			
			—	15·10	2667	2619			
			—	15·35	2663	2620			
						2618	+ 55	1·02673	35·15
		300	*Ca.*	14·55	2675	2617			
			—	14·80	2672	2618			
			—	14·85	2670	2617			
			—	15·20	2666	2620			
			—	15·55	2660	2621			
						2619	+ 55	1·02674	35·16

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1895.	m.		° C.					‰
23	[July 30]	350	*Ca.*	14·60	2676	2619			
			—	14·85	2671	2618			
			—	15·10	2667	2619			
			—	15·35	2663	2620			
			—	15·60	2659	2621			
						2619	+ 55	1·02674	35·16
		400	*Ca.*	15·05	2661	2612			
			—	15·30	2660	2616			
			—	15·55	2658	2619			
			—	16·10	2645	2617			
			—	16·35	2643	2619			
						2617	+ 55	1·02672	35·14
		500	*Ca.*	14·45	2675	2616			
			—	14·95	2671	2620			
			—	15·35	2668	2625			
			—	15·75	2662	2627			
			—	15·95	2658	2627			
						2623	+ 55	1·02678	35·22
		600	*Ca.*	14·85	2672	2619			
			—	15·15	2669	2622			
			—	15·25	2667	2621			
			—	15·85	2657	2623			
			—	16·05	2652	2623			
						2622	+ 55	1·02677	35·20
July 30		700	*Ca.*	10·35	2748	2620			
[July 30]			—	10·70	2743	2621			
84° 34′ N			—	10·85	2740	2620			
74 17 E			—	11·35	2737	2624			
			—	11·65	2733	2625			
						2622	+ 55	1·02677	35·20
		800	*Ca.*	12·47	2715	2620			
			—	12·77	2700	2610	+ 70	1·02680	
			—	13·27	2698	2617			
			—	14·17	2695	2630			
			—	14·62	2692	2635	+ 40	1·02675	
			—	15·37	2689	[2646][1]			
			—	15·62	2688	[2650]			
			—	15·87	2685	[2652]			
			—	16·37	2681	[2658]			
			—	16·57	2680	[2661]			
						2622	+ 55	1·02677	35.20

[1] In this and the succeeding observations, there has evidently been some irregularity. Air-bubbles may perhaps have gathered on the body of the hydrometer.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1895.	m.		° C.					‰
23	July 31	800[1]	*Ca.*	11·67	2730	2622			
	[July 31]		—	11·97	2726	2623			
	84° 28′ N		—	12·52	2723	2626			
	75 56 E		—	12·67	2720	2628			
			—	12·97	2718	2631			
						2626	+ 55	1·02681	35·26
		850	*Ca.*	15·87	2671[3]	[2638]			
			—	16·52	2643	2623			
			—	16·67	2641	2624			
			—	16·87	2639	2626			
			—	17·12	2636	2628			
			—	17·27	2634	2629			
						2626	+ 55	1·02681	35·26
	[Aug. 6]	900	*Ca.*	16·87	2620	2607			
			—	17·12	2617	2610			
			—	17·62	2610	2612			
			—	17·82	2608	2615			
			—	18·07	2604	2616			
						2612	+ 55	1·02667	35·07
		950	*Ca.*	16·87	2634	2621			
			—	17·47	2621	2621			
			—	17·62	2618	2620			
			—	17·87	2613	2621			
			—	18·07	2610	2622			
						2621	+ 55	1·02676	35·19
	July 25	1000	*Ca.*	13·27	2710	2629	+ 70	1·02699	
	[July 25]		—	13·77	2708	2636			
			—	14·17	2701	2636			
			—	14·37	2700	2639			
			—	14·57	2694	2636			
			—	14·97	2691	2640	+ 40	1·02680	
						2636	+ 55	1·02691	35·39
		1100	*Ca.*	15·57	2666	2627	+ 70	1·02697	
			—	15·62	2671	2633			
			—	15·97	2670	2639			
			—	16·17	2672	2645			
			—	16·42	2670	2548	+ 40	1·02688	
						2638	+ 55	1·02693	35.41

[1] The men who hauled up were uncertain whether this was 800 or 830.
[3] A few air-bubbles adhered to the body of the hydrometer.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1895.	m.		° C.					‰
23	July 25	1200	*Ca.*	9·47	2758	2618	+ 70	1·02688	
	[July 25]		—	9·97	2758	2625			
			—	10·47	2753	2627			
			—	11·52	2748	2638			
			—	11·67	2747	2639	+ 40	1·02679	
						2629	+ 54	1·02683	35·28
		1300	*Ca.*	15·77	2650	2615			
			—	16·37	2643	2620			
			—	16·57	2641	2622			
			—	16·87	2638	2625			
			—	17·32	2631	2627			
						2622	+ 55	1·02677	35·20
	July 26	1400	*Ca.*	8·87	2759	2612	+ 70	1·02682	
	[July 26]		—	9·77	2753	2617			
			—	10·97	2744	2626			
			—	11·62	2738	2630			
			—	12·67	2730	2638	+ 40	1·02678	
						2625	+ 55	1·02680	35·24
		1500	*Ca.*	13·27	2695	2614			
			—	13·37	2699	2620			
			—	14·67	2702	[2646]			
			—	15·57	2702[1]	[2663]			
			—	16·27	2643	2618			
			—	16·77	2632	2617			
			—	17·57	2618	2619			
			—	17·97	2608	2618			
			—	18·32	2603	2621			
						2618	+ 55	1·02673	35·15
		1600	*Ca.*	10·27	2749	2620			
			—	10·87	2744	2624			
			—	11·07	2740	2623			
			—	12·27	2730	2631	+ 40	1·02671	
			—	14·37	2680	2619	+ 70	1·02689	
			—	15·07	2675	2626			
						2624	+ 55	1·02679	35·23

[1] Some small air-bubbles had gathered on the body of the hydrometer; this observation and the preceding one are therefore erroneous.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydrometer.	Reading referred to 17·5° C.	Correction.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1895	m.		° C.					‰
23	July 26	1700	*Ca.*	18·57	2589	2612	+ 70	1·02682	
	[July 26]		—	18·67	2590	2615			
			—	18·87	2590	2619			
			—	19·07	2586	2620			
			—	19·27	2585	2623			
			—	19·67	2580	2628	+ 40	1·02668	
						2620	+ 55	1·02675	35·18
24	Nov. 30	150	*Ca.*	13·32	2654	2574			
	[Dec. 2]		—	13·87	2647	2577			
	85° 29′ N		—	14·17	2643	2578			
	58 44 E		—	14·62	2637	2580			
			—	15·27	2628	2583			
						2678	+ 55	1·02633	34·62
	[Dec. 3]	200	*Ca.*	9·72	2736[1]	2600			
			—	9·92	2733[1]	2600			
			—	10·27	2730[1]	2601			
			—	10·77	2720[1]	2599			
			—	11·27	2714	2600			
			—	11·37	2714[1]	2602			
						2600	+ 55	1·02655	34·91
		250	*Ca.*	9·77	2738	2602			
			—	9·87	2736	2602			
			—	10·32	2730	2602			
			—	10·47	2727	2601			
			—	10·82	2722	2602			
						2502	+ 55	1·02657	34·94
	[Dec. 2]	250	*Ca.*	11·07	2725[1]	2608			
			—	11·47	2720	2610			
			—	11·87	2715[1]	2610			
			—	12·47	2707	2612			
			—	12·77	2703	2613			
						2611	+ 55	1·02666	35·06
	Dec. 2	450	*Ca.*	10·12	27·47[1]	2616			
	[Dec. 3]		—	10·42	27·43	2617			
	85° 28′ N		—	10·77	27·40	2619			
	57 45 E		—	11·02	27·35[1]	2618			
			—	11·37	27·31	2619			
						2618	+ 55	1·02673	35·15

[1] Stem wiped.

Number of Temp.-Series	Date and Locality.	Depth in Metr.	Designation of Thermom.	Corr. Temp. of Water-Sample.	Reading of Hydro-meter.	Reading referred to 17·5° C.	Correc-tion.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity.
	1895.	m.		° C.					‰
24	Dec. 2	550	*Ca.*	11·17	2730[1]	2615			
	[Dec. 3]		—	12·37	2713	2616			
	85° 28′ N		—	12·92	2706	2618			
	57 45 E		—	13·37	2700	2620			
						2617	+ 55	1·02672	35·14
		800	*Ca.*	6·82	2788[1]	2617			
			—	7·17	2782	2615			
			—	8·47	2771[1]	2619			
			—	8·97	2760[1]	2615			
			—	9·17	2757	2613			
						2616	+ 54	1·02670	35·11
		850	*Ca.*	6·57	2780[1]	2606			
			—	7·17	2773[1]	2606			
			—	7·47	2770	2606			
			—	7·87	2765	2606			
			—	8·17	2761	2605			
						2606	+ 54	1·02660	34·98
		900	*Ca.*	7·27	2778[1]	2612			
			—	7·57	2774	2611			
			—	7·87	2771	2612			
			—	8·02	2772[1]	2615			
			—	8·47	2770[1]	2618			
						2614	+ 54	1·02668	35·08
		1900	*Ca.*	8·57	2719[1]	2569			
			—	9·47	2714	2575			
			—	9·97	2709	2577			
			—	10·17	2706[1]	2577			
			—	10·67	2700	2578			
						2575	+ 55	1·02630	34·58

[1] Stem wiped.

C. OBSERVATIONS WITH TORNØE'S APPARATUS FOR DETERMINATION OF THE SALINITY OF SEA-WATER BY ITS POWER OF ELECTRICAL CONDUCTIVITY.

When we started on our expedition in 1893, only two methods, viz. titration and floating hydrometers, had generally been used on board ship for determining the salinity (chlorine) or the specific gravity of the sea-water. The first of these methods, the method of titration, which has since that time been used with so much success by Prof. Otto Pettersson, as well as by Mr. Martin Knudsen of the Danish Ingolf Expedition, was not, I considered, to be thought of for an expedition of such a character and such long duration as ours. The solution of nitrate of silver could not be made on board with the necessary accuracy, even if distilled water were always available; and moreover, this method could hardly be expected to give very accurate results when used on board ship in the arctic regions, where, under ordinary circumstances, it is impossible to keep a fairly uniform temperature in the laboratory. Finally, I believed that the results of several previous expeditions proved that determinations made by various investigators may differ considerably, unless these determinations be repeatedly checked by controlling tests on samples of 'standard-water', as lately proposed by Mr. Martin Knudsen[1] and by Prof. Pettersson, in which case, however, a high degree of accuracy might be attained.[2] Considering it imperative not to make the numerous investigations on board the Fram more multifarious than was absolutely necessary, I therefore excluded titrations from the list.

It is a well known fact that it has hitherto been impossible to attain a high degree of accuracy in determinations of the specific gravity of sea-water

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[1] See: 'Conférence internationale pour l'Exploration de la Mer, réunie à Stockholm 1899, Stockholm, 1899, pp. XLII—XLVI.

[2] In my opinion, this extremely convenient method deserves to be strongly recommended to future expeditions. According to recent experiments of Mr. Helland-Hansen of the Norwegian Oceanic Survey, and myself, the mean differences between various determinations made by titration under favourable circumstances of the same water-sample will only amount to about 0·018 $^0/_{00}$, if every tenth determination in a series be controlled by tests on standard water. If an expedition cannot carry standard water, or if this is spoilt, *e. g.* by freezing, it is very easy at any moment to procure new standard water, by taking a large sample of sea-water, and determining its specific gravity carefully with a hydrometer of total immersion, by which method an accuracy of at least $\pm$ 0·005 $^0/_{00}$ might easily be attained, and if desirable even a higher degree of accuracy.

by the floating hydrometer. Errors of as much as 0·0002, or even 0·0003 may occasionally occur, as I think may be inferred from my investigations upon the errors of the hydrometer (see Memoir X).

Considering it very important to determine the specific gravity or salinity of the water of the North Polar Sea with the highest possible degree of accuracy. I asked Mr. *Hercules Tornøe* to help me in the matter, which he did in a most friendly manner. He constructed for the expedition an apparatus for the determination of the salinity of sea-water by its power of electrical conductivity, which he has himself described in 'Nyt Magazin for Naturvidenskaberne', Christiania, 1893.

Referring the reader to Tornøe's paper, I will here only say that the electrical conductivity or resistance of a certain volume of the water-sample at an accurately determined temperature is measured by alternating currents and a telephone in a Wheatstone's slide-wire bridge. This method can easily be used on board ship in all kinds of weather, if there is not too much disturbing noise; and it promised to give a considerably higher degree of accuracy than the methods previously employed on expeditions. According to my experience with the apparatus, I quite agree with Tornøe, when he asserts that by this method one can easily and in a short time determine the salinity of sea-water with an accuracy of at least about 0·05 *per mille.*[1] In some of my series of observations there are, however, greater disagreements, but these are evidently due to some occasionally occurring irregularities in the apparatus. They seem chiefly to have been due to irregularities in the contacts of the standards of resistance (rheostat) used.[2] Inaccuracies may to some extent also have been caused by a defective insulation of the electrodes, or occasionally even by air-bubbles adhering to them.

One drawback of this method is, as Tornøe has pointed out, that the calculation of the observation requires a good deal of time before the salinity can be found. Another drawback is, that it requires a standard solution of chloride of potassium, as one can never be quite certain that such a solution has not undergone alteration if the expedition lasts for some time; and on polar

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[1] Attention might here also be drawn to the possibility which Tornøe's method affords of determining the salinity and temperature of the sea-water *in situ*, without taking water-samples.

[2] The rheostat was of the pattern of Hartmann and Braun in Frankfort, with bifilar coils.

expeditions there is moreover the difficulty of having to protect the solution from the possibility of freezing. Our standard solution of chloride of potassium (35 ‰) was carried in small bottles, containing about 100 cubic centimetres each, and closed with india-rubber stoppers. During the first winter, 1893 and 1894, this standard solution was unfortunately frozen in all the bottles, which were lying in a locker in the laboratory. I considered the standard solution to be of no use henceforward, but nevertheless made observations with Tornøe's apparatus during April and May, 1894, when I decided to use it no more, as I found that it worked somewhat irregularly; and I then preferred to spend more time on the determinations, with the hydrometer, of the specific gravity of the water-samples, in order to make them as accurate as possible.

After the standard solution had frozen, there was only one bottle left which was perfectly full, and the india-rubber stopper of which seemed to have remained firmly fixed in its original position. The sample of standard solution contained in this bottle might therefore be expected to have been practically unaltered. Slight traces of crystalized salt outside the india-rubber stopper and round the lip of the bottle seemed, however, to indicate that a little brine might have been pressed out by freezing, and the salinity of the solution might thus have been slightly altered. On the 30th May, 1894, I made a series of observations with this sample of standard solution, in order to determine the constants of Tornøe's apparatus. The results thus obtained have been used for calculating the observations of the sea-water made in April and May, 1894, and I find that for observations taken between April 26th and May 30th, 1894, these calculations give, with few exceptions, very probable salinities, although they may be a trifle too high. For earlier dates of April (April 18th to 24th), these calculations evidently give too high salinities; and it appears that the constants of the apparatus had gradually changed during these days. I have therefore been obliged to reduce the constants of the apparatus for the calculation of the observations made on April 18th to 24th. See the table below.

TABLE.

The columns in the following table give:

First column. The distinguishing Number of the Temperature-Series; see Table, pp. 108 *et seq.*

Second column. The Dates when the Water-Sample was taken; and, in brackets, the Dates when the Observations were made.

Third column. The Depth in Metres from which the Water-Sample came.

Fourth and fifth column. Determinations of the Salinity, *per mille*, made by Tornøe's Apparatus. The mean value of all determinations of the same water-sample are given in the fifth column, after the exclusion of those marked with a query, which indicates that there has been some irregularity in the apparatus.

Sixth column. Salinity of the same Water-Sample, as deduced from determinations with the Hydrometer.

Seventh column. Difference between the Values obtained by the two methods of Observation.

TABLE

SHOWING THE DETERMINATIONS OF THE SALINITY OF THE SEA-WATER MADE WITH TORNØE'S APPARATUS.

WHEN NOT OTHERWISE STATED, THE OBSERVATIONS WERE MADE BY NANSEN.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
	1893.	m	‰	‰		The constant of the apparatus was not determined by controlling tests on the standard solution of chloride of potassium on this day; the constant found on the following day, July 24th, had therefore to be used for the calculations of the salinities.
2	July 23 9·15 p. m.	20	34·62 34·67[1] 34·62 } 34·64	34·64	0·00	
		40	34·75 34·74[1] 34·91 34·95 } 34·84	34·73	+ 0·11	
		60	34·88 34·75 } 34·82	34·82	0·00	
		80	34·91 35·11 } 35·01	34·90	+ 0·11	
		100	34·78 34·83 34·76 } 34·79	34·95	− 0·16	
3	July 24 10 p. m.	0	34·46 34·46			
		20	34·62 34·62	34·41	+ 0·21	
		40	34·78 34·95 } 34·87			
		60	34·27 34·42 } 34·35 ?			
		80	35·14 35·14	34·86	+ 0·28	
		100	34·89 34·94 } 34·92			
		120	34·87 35·22 } 35·05			
3 a	July 25 9 a. m.	126·5	36·28 ? 35·30 ? 35·04 35·04			

[1] Observation made by Capt. Scott-Hansen.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
	1893.	m	‰	‰		The constant found on July 24th had to be used for the calculation of all observations on this day.
4	July 25 6 p. m.	0	31·18 31·18			
		10	33·56, 33·47 } 33·52			
		20	34·21, 34·32 } 34·26			
		30	34·26, 34·19 } 34·22			
		40	34·77, 34·95, 34·63 } 34·78			
		60	34·82, 34·99, 34·98 } 34·93			
		70	35·16, 35·13 } 35·15			
5	July 27 0·20 p. m.	0	23·35, 23·36, 23·50?, 23·37 } 23·36	23·35	+ 0·01	
		5	28·43, 28·52, 28·44 } 28·46	28·32	+ 0·14	
		10	30·35, 30·29 } 30·32	30·39	− 0·07	
		14·5	34·00, 34·08, 33·87 } 33·98	34·03	− 0·05	
		20	34·47, 34·53 } 34·50	34·37	+ 0·13	
		30	34·68, 34·66 } 34·67	34·64	+ 0·03	
		40	34·73, 34·56?, 34·73 } 34·73	34·70	+ 0·03	
		50	34·69, 34·62, 34·67 } 34·66	33·74	− 0·08	

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
	1893.	m	$^0/_{00}$			As no controlling tests were made on the standard solution on July 28th, the constant found for the apparatus on July 27th had to be used for the calculation of all observations on this day. This is evidently the reason why the salinities found are lower than those found by the hydrometer.
6	July 28 9 p. m.	0	3·45, 3·46, 3·48, 3·48, 3·49 } 3·47			
		5	31·23, 31·18, 31·12 } 31·18	31·68	—0·50?	
		10	33·97, 33·94, 33·86 } 33·92	34·05	— 0·13	
		15	34·13, 33·96 } 34·04	34·10	— 0·06	
		20	33·93, 33·93, 33·85 } 33·90	34·36	—0·46?	
9	Oct. 9 [Oct. 17]	0	30·33?, 28·65, 28·75 } 28·70			
		20	29·26, 29·26, 29·39 } 29·30; 29·78?; [35·93?]	29·39	— 0·09	
		100	32·87, 33·03, 32·97 } 32·96			
		120	33·69, 33·71, 33·59 } 33·66 [1]	33·80	— 0·14	
		145	33·89, 34·02, 33·76 } 33·89 [1]	34·19	—0·30?	

[1] According to the record in the journal, these two series of determinations would give for 120 m. 34·63 $^0/_{00}$, and for 145 m. 34·85 $^0/_{00}$; but as these results differ so much from those obtained by the hydrometer, I assume that the plug for the resistance of one ohm has not been fixed firmly, and therefore this resistance has been inserted, and I thus obtain the above results.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
	1893.	m	‰			
11	Nov. 9	0·5	28·21 28·27 28·51 28·52 28·45 28·43 28·38 } 28·40			
10			28·21 28·19 28·43 28·38 28·35 28·35 28·40 } 28·33			
20			28·46 28·46 28·47 28·40 28·49 } 28·46			
30			29·05 29·09 29·15 } 29·10			
		40	31·13 31·15 31·16 } 31·15			
		51	32·10 32·14 32·22 } 32·15			
	1894.					
14	April 14 [April 18]	0·5	30·12 30·03 30·18? 30·11 30·10 } 30·09 [30·65] [1]	30·02	+ 0·07	If all observations made on April 18th, 19th, and 21st, were calculated with the same constant of Tornøe's apparatus as that found on May 30th, and used for observations made after April 26th, we obtain salinities which are evidently much too high, and which
	April 21 [April 21]	1	29·72 29·80 29·76 } 29·76 [30·31]	29·58	+ 0·18	

[1] The salinities added in brackets in this column, for depths between 0·5 m. and 1200 m., are the values obtained by using for the calculations the same constant of the apparatus as that found on May 30th, 1894 (see p. 199), and used for all subsequent observations.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.		Salinity found by Hydrometer.	Difference.	Remarks.
	1894.	m	‰		‰		are here given in brackets, (fifth column), *e. g.* for 0·5 m. 30·65 ‰, while we have found 30·02 ‰ by the hydrometer. All observations with Tornøe's apparatus for depths between 0·5 m. and 250 m. (made on April 18th, 19th, and 21st) have therefore been reduced by the same factor, which was found by taking the mean of all simultaneous observations made with the hydrometer.
14	April 14 [April 18]	20	29·70? 29·75? 29·76? 29·83[1] 29·85 29·83	29·79 [30·34]	29·74	+ 0·05	
		40	31·35 31·27 31·35 31·27 31·27	31·30 [31·90]	31·39	− 0·09	
	April 15 [April 19]	80	33·83 34·08? 33·95 33·75 33·76 33·71	33·85 [34·48]	33·86	− 0·01	
		100	34·39 34·33 34·24 34·17 34·21	34·27 [34·93]	34·15	+ 0·12	
		120	34·52 34·49 34·56 34·45 34·48 34·40 34·39	34·47 [35·13]	34·49	− 0·02	
		140	34·63 34·58 34·62 34·61 34·61 34·60	34·61 [35·28]	34·78	− 0·17	
		160	34·06 34·03 34·04 34·10	34·06? [34·71]	33·72?	+ 0·34	

[1] Before this observation, the apparatus was washed to remove the air-bubbles adhering to the electrodes: the subsequent observations are therefore more trustworthy.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
	1894.	m	‰	‰		
14	April 15 [April 19]	180	34·55, 34·54, 34·60, 34·48 } 34·54 [35·20]	34·72	— 0·18	
		200	[33·23?] [33·20?] 34·75, 34·78 } 34·77 [35·42]	34·76	+ 0·01	
		250	35·06, 35·02, 35·06, 34·98, 34·92 } 35·01 [35·68]	35·01	0·00	
	April 21 [April 23]	250	35·17, 35·08, 34·97, 35·09, 35·09, 35·04 } 35·07 [35·41]	34·97	+ 0·10	The following salinities found by Tornøe's apparatus for the depths between 250 m. and 600 m. have been reduced by a smaller factor than the above salinities for depths between 0·5 m. and 250 m., as there is here less difference between the values (in brackets) found by calculation with the constant of the apparatus of May 30th (see p. 199), and those found by the hydrometer·
	April 23 [April 24]	250	35·17, 35·23, 35·10, 35·10, 35·20 } 35·16 [35·50]	35·22	— 0·06	
		300	35·16, 35·12, 35·14, 35·15, 35·09 } 35·13 [35·47]	35·12	— 0·05	
		300[1]	36·59? 34·96, 35·00, 35·03, 34·95 } 35·01 [35·35]			
		400	35·21, 35·20, 35·14 } 35·18 [35·52]	35·26	— 0·08	

[1] This sample was taken some hours after the preceding sample from 300 m. For the hydrometer determination, both samples were mixed.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
14	1894.	m.	‰	‰		
	April 23 [April 24]	500	35·46, 35·59, 35·61 } 35·55 [35·91]	35·22	+ 0·33	
		600	35·49?, 35·28, 35·33 } 35·31 [35·72]	35·18	+ 0·13	
	April 24 [April 25]	800	35·55, 35·48, 35·45, 35·43 } 35·48? [35·69]	35·35	+ 0·13	The observations taken on this day, of the water-samples from 800 m., 1000 m. and 1200 m., give lower values (see figures in brackets) — calculated with the constant of May 30th (see p. 199), — than previous observations. They have therefore been reduced with a still smaller factor than the one given above.
		1000	35·16, 35·13, 35·08, 35·21 } 35·15 [35·35]	35·29	— 0·14	
		1200	35·29, 35·24, 35·29, 35·15 } 35·24 [35·44]	35·24	0·00	
	April 26 [April 27]	1400	35·26, 35·05, 35·07, 35·00 } 35·10	35·47?	—0·12?	All succeeding observations made with Tornøe's apparatus have been calculated with the constant found on May 30th (see p. 199). The only exceptions are the observations made on May 24th, for depths between 60 m. and 200 m., which gave too high values, and had therefore to be reduced.
		1400	35·65?, 35·57?, 35·57? } 35·60?			
		1600	35·52?, 35·52?, 35·50?, 35·42?, 35·13	35·28		
		1600	35·20, 35·18, 35·12, 35·10, 35·09 } 35·14	35·28	— 0·14	
	April 25 [April 26]	1800	35·25, 35·24, 35·23, 35·15, 35·07[1] } 35·19	35·28	— 0·07	

[1] For this determination, Tornøe's apparatus was filled with new water from the same water-sample as above.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
	1894.	m.	‰	‰		
14	April 25 [April 26]	2000	35·19, 35·27, 35·27, 35·21 } 35·23			
		2200	35·16, 35·08, 35·13, 35·16 } 35·13	35·18	— 0·05	
		2400	35·30, 35·29, 35·33, 35·25, 35·34, 35·25, 35·23 } 35·28	35·37	— 0·09	It is noted in my journal that this sample was taken with special care, the glass-bottle being well rinsed beforehand, etc., etc.
15	May 22 [May 23]	0·4	27·96? 30·44, 30·61 } 30·53?	30·05	+0·48?	
		10	30·56, 30·55, 30·48 } 30·53	30·40	+ 0·13	
		20	30·52, 30·41, 30·81?, 30·32 } 30·42	30·22	+ 0·20	
		40	32·48, 32·57, 32·41 } 32·49	32·35	+ 0·14	
	[May 24]	60	33·59, 33·51, 33·70 } 33·60 [34·69]	33·70	— 0·10	There has been some irregularity with Tornøe's apparatus on this day, as all observations for depths between 60 m. and 200 m. have values that are evidently much too high (the figures in brackets in fifth column), if the observations are calculated with the same constant (of May 30th) as the previous and subsequent observations. All observations on this day, for depths between 60 m. and 200 m., have therefore been re-
		80	34·16, 33·99, 33·95 } 34·03 [35·13]	34·18	— 0·15	
		100	34·61, 34·58, 34·47 } 34·55 [35·68]	34·28	+ 0·27	
		120	34·74, 34·60 } 34·67 [35·81]	34·40	+ 0·27	

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
	1894.	m.	‰	‰		duced by a factor found by taking the mean of all simultaneous observations with the hydrometer.
15	[May 24]	160	34·57 34·46 34·41 34·51 34·24? } 34·49 [35·63]	34·68	— 0·19	
		200	34·73 34·76 34·59 } 34·69 [35·84]	34·76	— 0·07	
	May 23 [May 25]	240	35·49? 35·43 35·43 35·32 35·97? 36·12? 35·33 35·28 35·32 } 35·35			
		300	35·28 35·40 35·37 } 35·35	34·98	+0·37?	
		400	35·35 35·26 35·28 } 35·30	35·06	+ 0·24	
		500	35·19 35·25 35·28 } 35·24	35·03	+ 0·21	
		600	35·30 35·28 35·10 } 35·23	35·03	+ 0·20	
	May 24 [May 25]	700	35·03 35·12[1] 35·03 } 35·06	35·01	+ 0·05	
		800	35·24 35·43?[1] 35·21 } 35·23			

[1] During these observations, the metal plug for 2 ohms was removed in the rheostat, and some irregularity has evidently occurred in this resistance-coil, commencing during the observations of the water-sample from 700 m., and increasing during the succeeding observations, while it was not noticeable during the previous observations from depths of less than 700 m. In the observations of the samples from depths below 1600 m., on May 30th, no such difference occurs.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.		Salinity found by Hydrometer.	Difference.	Remarks.
	1894.	m.	‰		‰		
15	[May 26]	800	35·17 35·48?[1] 35·17 35·23	35·19			
		900	35·27 35·63?[1] 35·30	35·29			
		1000	35·06 35·07 35·41[1] 55·48 35·44 35·50 35·87?[1] 36·06?[1]	35·33	35·03	+ 0·30	
		1200	35·33 35·87?[1]	35·33			
		1400	35·33 35·51 35·21	35·27	35·12	+ 0·15	
May 25 [May 26]		1600	35·21 35·25 35·42?[1] 35·13	35·20	35·08	+ 0·12	
		1600	35·01 35·27[1] 35·38[1] 35·28[1] 35·08 35·20[1]	35·20			
May 25 [May 30]		1600	35·32 35·32 35·26 35·34 35·33	35·31	35·08	+ 0·23	

[1] During these observations, the metal plug for 2 ohms was removed in the rheostat, and some irregularity has evidently occurred in this resistance-coil, commencing during the observations of the water-sample from 700 m., and increasing during the succeeding observations, while it was not noticeable during the previous observations from depths of less than 700 m. In the observations of the samples from depths below 1600 m., on May 30th, no such difference occurs.

Number of Temp.-Series	Date.	Depth in Metr.	Salinity determined with Tornøe's Apparatus.	Salinity found by Hydrometer.	Difference.	Remarks.
	1894.	m.	‰	‰		
15	May 25 [May 30]	1800	35·25, 35·18, 35·15 } 35·19			
		2000	35·23, 35·24, 35·18 } 35·22	35·10	+ 0·12	
		2200	35·22, 35·36, 35·39, 35·33 } 35·33	35·26	+ 0·07	
	May 26 [May 30]	2400[1]	34·07, 34·08, 34·04, 34·13 } 34·08	34·19	+ 0·11	

[1] This depth is evidently wrong, as the salinity found is much too low. The water-bottle has probably been accidentally closed in some water-stratum near the surface.

D. ANALYSES OF WATER SAMPLES FROM THE NORTH POLAR BASIN.

According to my original programme, it had been my intention to bottle water-samples from the various strata of the sea, for determination of the ratios in which the principal saline components of the North Polar sea-water stand to one another; and I had taken special bottles with glass stoppers for this purpose. Having had on opportunity of bottling such samples before I left the Fram in March, 1895, I asked Dr. Blessing to do so later. As there was a possibility that organic life or decomposition of organic matter might cause slight alterations in the relation between the various salts of the water-samples in the bottles, I asked him to sterilise them by boiling.

On the 30th November and the 2nd December, 1895, Dr. Blessing took ten water-samples, with Blessing's water-bottle, from depths between 150 m. and 1900 m. After their specific gravities had been determined with the hydrometer Åderman No. 2 (see table, p. 195), the water-samples were poured into ten glass bottles (with a capacity of about 500 cubic centimetres) with glass stoppers, and were placed for sterilisation in boiling water, where they remained for half an hour without reaching boiling point.[1] The bottles were then taken out, and their glass stoppers carefully soldered with paraffine.

When these water-samples were taken out for examination in 1898, nine bottles seemed to be in perfectly good condition, and the paraffine soldering in its original state, without any visible crack. One bottle containing a water-sample from 550 metres, had been cracked, and this sample was therefore discarded.

The Specific Gravity of the Water-Samples.

Mr. Hercules Tornøe did me the great favour to determine, with a high degree of accuracy, the specific gravity of five of these samples from 150 m., 200 m., 250 m., 800 m., and 850 m. Two determinations were made of

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[1] The bottles were immersed in the boiling water to just below their necks; there was thus no possibility that boiling water could get inside them. As the bottles were closed with the glass stoppers during the sterilisation, it is not probable that the specific gravity of the water-samples has been appreciably increased by evaporation. There was no deposit to be seen in the water in the bottles, when they were afterwards examined.

each sample with the Sprengel pycnometer, all weighings were reduced to vacuo, and we may be certain of the figures up to the fifth decimal place of the specific gravity found. Without knowing the results of Tornøe's determinations, Mr. O. N. Heidenreich afterwards determined by gravimetric analysis the amount of chlorine (or halogen) in the same water-samples, and calculated their salinity, using the factor 1·810. It will be seen in the table below, that the mean difference between the two series of observations is 0·06 ‰, Heidenreich's salinities being lower than Tornøe's. The cause of this fairly uniform difference is probably that the factors used for finding the salinity, either from the amount of chlorine or from the specific gravity, are not quite correct.

Heidenreich had previously determined the specific gravity of the four other water-samples from 250 m., 450 m., 900 m., and 1900 m. As the determinations were made with an ordinary bottle-pycnometer, with thermometer, and as the weighings were not referred to vacuo, these determinations are not so accurate as those made by Tornøe.[1]

[1] As the specific gravities ($S \frac{17{\cdot}5^\circ C.}{17{\cdot}5^\circ C.}$) originally found by Heidenreich were on the whole higher than those found by Tornøe, from similar depths, the latter had the great kindness to examine the same samples with his Sprengel pycnometer. The results of the determinations of $S \frac{17{\cdot}5^\circ C.}{17{\cdot}5^\circ C.}$ by the two investigators were the following:

Depth	Determinations by Heidenreich	Determinations by Tornøe	Difference
250 m....	1·02671	1·02681	0·00010
450 m....	2687	2692	0·00005
900 m....	2678	2689	0·00011
1900 m....	2646	2659	0·00013

The specific gravities found by Tornøe are considerably higher than those found by Heidenreich; but as the determinations by the former were made several months after the bottles had first been opened by Heidenreich, and as there was little water left in each bottle, the probability is that the specific gravity of the samples had been somewhat increased by evaporation in the mean time, so that the specific gravities found by Tornøe have no absolute value. Colonies of fungi had also formed, especially on the sample from 1900 m. If we assume that the increase of specific gravity has been about the same in each sample, the determinations seem to indicate a similar mutual difference between the various samples as found by Heidenreich, the specific gravity of the sample from 450 m. being higher (0·00011 and 0·00003) than that of the samples from 250 m. and 900 m., though not so much as found by Heidenreich (differences = 0·00016 and 0·00009), while that of the sample from 1900 m. is considerably lower. *A priori* we might expect the water-samples from 900 m. to have had the same specific gravity as the samples from 800 m. and 850 m., provided that the water-bottle has worked properly; but if so, Heidenreich's originally-found specific gravity (= 1·02678) is about 0·000045 too high. It is not certain that the two

The results of the above-mentioned determinations are given in the following table.

Table showing determinations made of 9 water-samples, taken by Dr. Blessing on November 30th and December 2nd, 1895.[1]

The determinations marked with an *asterisk* are made by *Tornøe,* and may be considered absolutely accurate. The other determinations are made by *O. N. Heidenreich.*

Depth in Metres from which Sample came	Determinations with Pycnometer		Determinations by Gravimetric Analysis		Difference between the Salinities found by the two Kinds of Determinations
	$S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C}$	Salinity	Amount of Chlorine	Salinity deduced from Amount of Chlorine	
150 m. . . .	*1·02629	*34·57 ‰	19·049 ‰	34·48 ‰	0·09 ‰
200 - . . .	* 2654	*34·90 -	19·243 -	34·83 -	0·07 -
250 - . . .	* 2664	*35·03 -	19·321 -	34·97 -	0·06 -
250 - . . .	2665	35·05 -			
450 - . . .	2681	35·25 -			
800 - . . .	* 2673	*35·15 -	19·402 -	35·11 -	0·04 -
850 - . . .	* 2674	*35·16 -	19·394 -	35·10 -	0·06 -
900 - . . .	2672	35·14 -			
1900 - ? .	2640	34·71 -			

The above determinations seem to give very probable results, especially those marked with an *asterisk,* which are absolutely trustworthy. With the exception of the sample from 1900 m., the above results agree fairly well with the determinations made on board from similar depths with the hydrometer, during the course of the expedition, though they are on the whole somewhat low. The specific gravity of the sample from 1900 m. is evidently much too low, and the probability is that the water-bottle has not worked properly in this case. The sample cannot therefore be considered as being from 1900 m. but is either from some stratum above 200 m. or the water-bottle has not been tightly closed.

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samples from 250 m. have had the same specific gravity, as they were taken at different times, and frequent variations were observed at this depth. Nevertheless the difference of 0·00007 between Heidenreich's original value (1·02681) and Tornøe's (1·02664) for the specific gravity of the two samples, seems to agree fairly well with the difference found for the samples from 800 m., 850 m., and 900 m. I have therefore assumed that Heidenreich's first determinations with the pycnometer have given, on the whole, 0·0006 too high values of the specific gravity, and I have corrected them accordingly in the final table above.

[1] Cf. Blessing's own determinations of the same water-samples, pp. 195, 196.

The Quantities of some Principal Saline Components of the Water-Samples.

The quantities of chlorine or halogen, sulphuric acid, lime, and magnesia present in the Fram water-samples were determined by Mr. O. N. Heidenreich with the results given in the following table. The methods used for the analyses were the same as those described by Mr. Ludvig Schmelck in the report of the "Norwegian North Atlantic Expedition 1876—1878", vol. IX, Chemistry, pp. 5—9. The amount of chlorine (or halogen) was determined by gravimetric analysis. The size of the water-samples was about 400 cubic cm. When the bottles were opened, no smell of sulphuretted hydrogen could be detected.

Table showing the quantities per 100 parts of Sea-Water, of the Principal Saline Components present in the Fram Samples.

(For purposes of comparison, the mean values found by Schmelck for the same saline components in water-samples from the North Atlantic have been added below.)

Depth from which the Samples came	Chlorin	SO_3	CaO	MgO	Total Salts calculated from the Quantity of Chlorine	Total Salts calculated from $S\ \frac{17{\cdot}5^\circ C.}{17{\cdot}5^\circ C.}$
	%	%	%	%	%	%
150 m. . . .	1·905	0·2209	0·0559	0·2215	3·448	3·457
200 - . . .	1·924	0·2217	0·0563	0·2226	3·482	3·490
250 - . . .	1·932	0·2199	0·0575	0·2159	3·497	3·503
250 -[1] . .	1·947	0·2250	0·0582	0·2290	3·524 ?	3·526
450 -[1] . .	1·953	0·2222	0·0583	0·2164	3·535 ?	3·540
800 - . . .	1·940	0·2251	0·0583	0·2114	3·511	3·515
850 - . . .	1·939	0·2264	0·0580	0·2160	3·510	3·516
900 -[1] . .	1·952	0·2220	0·0583	0·2108	3·533 ?	3·536
1900 -[1] . .	1·945	0·2227	0·0581	0·2182	3·520 ?	3·497 ?
Mean	1·937	0·2229	0·0577	0·2191	3·507	3·509
Schmelck, mean values for all depths of North Atlantic	1·932	0·2214	0·0578	0·2203	3·497	3·485 ?
Schmelck, mean values for intermediate depths of North Atlantic	1·934	0·2223	0·0577	0·2200	3·501	3·498

[1] These samples are from the bottles which had first been opened by Mr. Heidenreich, and afterwards examined by Mr. Tornøe (see p. 213). As the above analyses were made after Tornøe had examined the bottles, the quantities of the Saline Components and Total Salts found to be present in these water-samples cannot be considered trust-

As the individual water-samples only amounted to about 400 cubic-centimetres in volume, the above analyses can hardly pretend to a very high degree of accuracy, and the differences between the values found for the various components are not greater than might in most cases be explained by observational errors. There are, however, differences, especially in the amounts of CaO, which may be partly due to natural causes.

If we calculate the amount of Total Salts from the specific gravities (found by the Sprengel pycnometer), by the formula Percentage of Total Salts $= (S \frac{17{\cdot}5^\circ C.}{17{\cdot}5^\circ C.} - 1) \times 1315$, the above analyses will give the following values of the percentage of the principal saline components in 100 parts of Total Salts.

In 100 parts of Total Salts.

Depth of Water-Samples	Chlorine	SO_3	CaO	MgO
	%	%	%	%
150 m. . . .	55·107	6·390	1·617	6·407
200 - . . .	55·129	6 352	1·613	6·378
250 - . . .	55·153	6·278	1·642	6·163
250 - . . .	55·219	6·381	1·651	6·495
450 - . . .	55·170	6·277	1·647	6·113
800 - . . .	55·191	6·404	1·659	6·014
850 - . . .	55·149	6·439	1·650	6·143
900 - . . .	55·204	6·278	1·649	6·244
1900 - ?. .	55·256?	6·327?	1·651?	6·199?
Mean	55·175	6·347	1·642	6·240

Prof. Dittmar[1] found the following values for the percentage-composition of the dissolved material in 77 samples of sea-water collected by the Challenger Expedition from various localities and depths of the ocean.

In 100 parts of Total Salts.

	Chlorine	SO_3	CaO	MgO
Challenger	55·420	6·415	1·692	6·214
Fram	55·175	6·347	1·642	6·240

worthy, as some evaporation had evidently occurred after the bottles had first been opened (see foot-note on p. 213). Colonies of fungi had also formed in some of the bottles. The sample from 1900 m. in particular seems to have altered much.

[1] Report on the Scientific Results of the Voyage of H. M. S. Challenger, etc., Physics and Chemistry, Vol. I, 1884.

We see that Dittmar's values for the percentage of chlorine(halogen), sulphuric acid and lime, are higher than ours, while his value for magnesia is somewhat lower. The differences may seem so great as to be beyond the probable limits of the analytical errors; but I think it more probable that they are due, at least partly, to differences in the analytical methods employed. Thus, for instance, the factor 1·8058, found by Dittmar for referring the amount of halogen to the percentage of total salts in the sea-water, is probably somewhat too small. Dittmar himself also states that his percentage of lime is probably too high.[1] He has, however, pointed out a probable difference in this respect between his samples from shallow water and those from deeper strata, and a similar difference might perhaps also be traced in our samples.

Challenger	CaO in 100 parts of Total Salts	Fram	CaO in 100 parts of Total Salts
43 samples from shallow water.....	1·679	Mean of samples from 150 m. and 200 m.	1·615
34 samples from deep water.....	1·710	Mean of 6 samples from between 250 m. and 900 m.....	1·650
Difference	0·031	Difference	0·035

There seems to be a strange similarity in the differences in these two cases, but Dittmar himself, by more accurate analyses, found smaller differences in the percentage of lime in the upper and lower strata of the ocean than those stated above (see also later). Schmelck has also found a slightly higher percentage of lime at the bottom of the sea than in the higher strata (see later).

The following table gives the ratios in which the several principal saline components stand to 100 parts of halogen in the several water-samples from the Fram. In the same table are also given, for comparison, the similar values for the same saline components found by Forchhammer[2], Schmelck[3], Pettersson[4], Dittmar[5], and Hamberg[6].

[1] L. c., p. 37.
[2] Indbydelsesskrift til Kjöbenhavns Universitets Fest, etc. Copenhagen, 1859.
[3] The Norwegian North-Atlantic Expedition 1876–1878, Part IX, Chemistry, p. 12. Christiania, 1882.
[4] Vega-Exped. Vetensk. Iagttagelser, vol. II, p. 377. Stockholm, 1883.
[5] L. c., p. 26.
[6] Bihang till K. Svenska Vet.-Akad. Handl., vol. X, No. 13, 1885, p. 11.

Quantities of SO_3, CaO, and MgO with reference to 100 parts of Halogen.

Depth from which Samples came	SO_3 (Cl = 100)	CaO (Cl = 100)	MgO (Cl = 100)
150 m.....	11·596	2·934	11·627
200 -	11·523	2·926	11·570
250 -	11·382	2·976	11·175
250 -	11·556	2·989	11·762
450 -	11·377	2·985	11·081
800 -	11·603	3·005	10·897
850 -	11·676	2·991	11·140
900 -	11·373	2·987	11·312
1900 - ?	11·450?	2·987?	11·218?
Mean of all samples....	11·504	2·976	11·309
Mean of samples from 150 m. and 200 m. ...	11·56	2·930	11·60
Mean of 6 samples from 250 m. to 900 m.....	11·50	2·989	11·23
Forchhammer (surface)	11·88	2·93	11·03
Schmelck	11·46	2·99	11·40
Pettersson	11·70	3·03	11·49
Dittmar.....	11·576	3·053	11·212
Hamberg.....	11·485		

It will be seen that the mean results of the analyses of our water-samples agree best with Schmelck's values, the amount of lime being higher than Forchhammer's, but lower than Schmelck's, and still lower than Pettersson's and Dittmar's values, while our percentage of sulphuric acid is somewhat higher than Schmelck's and Hamberg's, but lower than the values of the others. Our percentage of magnesia is higher than the values found by Forchhammer and Dittmar, but lower than those of Schmelck and Pettersson. These differences may be partly due to natural causes, especially the differences in the percentage of lime and sulphuric acid, as the determinations of these components allow of a higher degree of accuracy than that of magnesia. I fear, however, that owing to the small number and quantities of our water-samples, the analyses are not complete enough to allow of any certain conclusions on this point.

According to investigations made by Prof. Pettersson[1] and Mr. Forsberg[2], "the formation of sea-ice is chemically a selective process", by which

[1] O. Pettersson, "On the Properties of Water and Ice". Vega-Expeditionens Vetenskapliga Iagttagelser, vol. II, pp. 304 *et seq.* Stockholm, 1883.

[2] G. E. Forsberg, "Om Hafsisens Salthalt". Öfvers. K. Vet.-Akad. Förhandl., No. 6, p. 53. Stockholm, 1884,

the sulphates predominantly enter into the solid state by freezing, and are thus retained in the ice formed, while the chlorides, and to some extent also the lime, are rejected by the ice, and will predominate in the brine. It might therefore be expected that polar sea-water, in which ice is continually being formed, would be comparatively rich in chlorides and lime, and comparatively poor in sulphates. No such marked difference seems, however, to exist between the mean results of our analyses and those of previous investigators; nor is there any such difference between the Fram water-samples from the upper water-strata and those from greater depths: if there is a difference, it seems rather to tend in the opposite direction. With regard to the origin of the water, there is certainly a distinct difference between the upper and the lower strata of the North Polar Basin, the upper strata, or those between the surface and 200 or 250 metres' depth, with comparatively low salinity (between 29 ‰ and 34·8 ‰), being what we might call polar water that has been partly diluted with water from the Siberian rivers, while the water between 250 metres and the bottom of the basin, with a high salinity (about 35·2 ‰), is of Atlantic origin. Now we find in the samples from 150 m. and 200 m. a smaller percentage of lime than in the samples from deeper strata, while no certain difference can be shown with regard to the percentage of sulphuric acid. This is exactly contrary to what might be expected, for both the freezing process and the admixture of river-water should tend to increase the percentage of lime. It should, however, be remembered that according to the vertical distribution of salinity and density in the North Polar Basin, the freezing process can only influence the composition of the water-strata very near the surface of the sea. My various series of determinations of the specific gravity and salinity of the sea-water prove that the water near the surface of the North Polar Basin may often have a higher salinity than the water-strata immediately below. This is evidently due to a concentration of the uppermost strata, caused by the freezing process and by the addition of brine gradually given off by the ice. In these uppermost strata we must therefore expect to find appreciable changes in the percentages of sulphuric acid, chlorine, and even lime; but these changes cannot possibly influence the composition of the sea-water much deeper than say 40 metres, and decidedly not deeper than 100 metres at the most; for the density of the water increases so rapidly with increasing depth, that the

water of the surface cannot possibly be so much concentrated by the freezing process as to become heavier than the water of these strata. The salinity of the surface-water between 0 m. and 10 m. is generally about 30 ‰ with a density ($S\frac{t}{4^\circ C.}$) of about 1·0241, while the salinity at 40 m. is generally above 32·3 ‰ with a density ($S\frac{t}{4^\circ C.}$) greater than 1·0260. At 60 m., where we have a minimum of temperature (about —1·8° C.), the density is about 1·0271, and at 100 m., with a temperature of about the same as near the surface (—1·6° C.), the salinity is above 34·4 ‰, and the density greater than 1·0276.

Thus we cannot expect any appreciable changes to have been brought about in the relation between the saline components in the polar water of depths of 150 m. and 200 m. in the North Polar Basin, by the formation or melting of ice on its surface. If, therefore, there are any real differences between the water-samples from these strata and those from deeper strata, we must assume them to have other causes.

We have stated above that there is a remarkable similarity in the difference between the samples from the upper and the deeper water-strata with regard to the percentage of lime, both in the Challenger samples and the Fram samples. Dittmar has, however, by supplementary analyses[1] found the differences to be less than stated above, as may be seen from the following table giving the mean ratio in which lime stands to 100 parts of halogen in water-samples from shallow water, intermediate depths, and deep water or the bottom of the sea, as found by Forchhammer, Schmelck, Dittmar, and Heidenreich.

Shallow water means, according to Forchhammer and Schmelck, the surface of the sea, according to Dittmar, depths of 50 fathoms or less, and according to Heidenreich, 150 m. and 200 m.

Intermediate depths mean, according to Schmelck, depths between the surface and the bottom, according to Dittmar, depths between 300 and 1000 fathoms, and according to Heidenreich, depths between 250 m. and 900 m.

Deep water means, according to Schmelck, the bottom of the sea, and according to Dittmar, depths greater than 1500 fathoms.

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[1] Dittmar, l. c. pp. 35 and 36.

Ratio in which CaO stands to 100 parts of Halogen in samples from

	Shallow Water	Δ	Intermediate Depths	Δ	Deep water
Forchhammer	2·93				
Schmelck (Norwegian North Atlantic)	2·98	·00	2·98	·03	3·01
Dittmar (Challenger samples)	3·018	·012	3·030	·001	3·031
Heidenreich (Fram samples).....	2·930	·059	2·989		

We see that in all these series there is a decided tendency towards a relatively lower amount of lime in the upper strata of the sea, this tendency being apparently most marked in the North Polar Basin, in spite of the fact that the upper strata of this sea are much diluted with river-water.

As I have said before, however, our material from the Fram is far too incomplete and meagre to admit of our drawing any certain conclusions, and we must certainly accept the above results with much hesitation. They seem to be in contradiction to Pettersson's results, as he found a relatively high percentage of lime (referred to 100 parts of halogen) in the four water-samples examined by him[1] from the Siberian shores of the Arctic Ocean (from depths between 7 m. and 128 m.). He found the mean amount of lime in relation to 100 parts of halogen to be 3·03, and this relative amount of lime increased towards the surface of the sea; at 7 metres he found it to be 3·14, while at 128 metres it was 2·97. The chief reason of this may be that the water near the surface has been largely diluted with river-water, the salinity at 7 m. being only 13·81 ‰. The rapid decrease of the relative amount of lime in a downward direction, might also indicate that even in this part of the North Polar Sea we might, at depths of 150 m. or 200 m., reach low values similar to the above. The amount, 2·97, found at 128 m. is even now, as we see, lower than 2·989 found as mean for the Fram samples from depths between 250 m. and 900 m.

[1] L. c. p. 377.

E. REMARKS ON THE ACCURACY OF OUR DETERMINATIONS OF THE SPECIFIC GRAVITY OF THE SEA-WATER.

In order to get some idea of the degree of accuracy which our determinations of the specific gravity ($S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$) or salinity of the water of the North Polar Basin might possess, we will make some comparisons between the results obtained by different and entirely independent methods.

Date	Depth from which the Samples came	Determinations with Tornøe's Apparatus		Determinations with Hydrometer $S\,\frac{17.5^\circ\,C.}{17.5^\circ\,C.}$	Difference
		Salinity	$S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$		
1893	m.	‰			
July 23	20	34·64	1·02634	1·02634	0·00000
	40	34·84	2650	2641	+ 00009
	60	34·82	2648	2648	00000
	80	35·01	2662	2654	+ 00008
	100	34·79	2646	2658	— 00012
July 24	20	34·62 [1]	1 02633 [1]	1·02617	+[0·00016?]
	80	35·14 [1]	2672 [1]	2651	+[00021?]
July 27	5	28·46	1·02164	* 1·02154	+ 0·00010
	10	30·32	2306	2311	— 00005
	14·5	33·98	2584	2588	— 00004
	20	34·50	2624	2614	+ 00010
	30	34·67	2637	2634	+ 00003
	40	34·73	2641	2639	+ 00002
	50	34·66	2636	2642	— 00006
July 28	5	31·18	1·02371	1·02409	—[0·00038] [2]
	10	33·92	2579	2589	— 00010
	15	34·04	2589	2593	— 00004
	20	33·90	2578	2613	—[00035] [3]
October 9	20	29·30	1·02228	* 1·02235	— 0·00007
	120	33·66 [4]	2560 [4]	* 2570	[— 00010]
	145	33·89 [4]	2577 [4]	* 2600	[— 00023]
				Mean	—0·000004

[1] As there is only one observation with Tornøe's apparatus for each of these two water-samples, the results cannot be considered very accurate.

[2] This difference is quite improbable, and there must be a mistake of some kind in one of the determinations.

[3] This difference is highly improbable. It may be that in the record of the journal of determination with the hydrometer, 1·02658 has been written instead of 1·02638, which, referred to $S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$, would give 1·02593 instead of 1·02613.

[4] These two determinations are somewhat doubtful (see p. 203, footnote).

During the first summer and autumn of the voyage of the Fram, the simultaneous determinations given in the preceding table, were made entirely independently of each other with Tornøe's electrical apparatus (see pp. 201—203) and with the hydrometers Åderman no. 2 and Küchler no. 4 (the latter determinations marked with an asterisk; see p. 166). The determinations of the salinity with Tornøe's apparatus have been referred to the corresponding $S\,\frac{17{\cdot}5^\circ\,C}{17{\cdot}5^\circ\,C}$.

We see that if the six observations be excluded, where the determinations with Tornøe's apparatus are doubtful — July 24th and October 9th — or where the differences between the two kinds of observations are manifestly absurd, we find a mean difference of 0·000004, the determinations with the hydrometers being higher than those with Tornøe's apparatus. If the mean of all observations be taken, we find this difference to be 0·000036, the determinations with the hydrometers being too high.

I have said on p. 21 in Memoir X, that a ship in motion will tend to give low indications of the hydrometer. This can, however, hardly be applied to the above observations taken in July, 1893, as the sea was very calm, and moreover, the Fram was very slow in her motions and free from shaking, the revolutions of the propeller causing no appreciable vibration in the strong and heavily-built ship. There is thus no probability that the indications of the hydrometers have been comparatively lower at this time than they were subsequently, after the ship had been frozen fast in the ice.

The determinations made with Tornøe's apparatus in 1894 are not so trustworthy as those of 1893 (cf. p. 199), but on May 30th, 1894, the constant of the apparatus was determined by tests on the standard solution of chloride of potassium (see p. 199). The determinations made with the apparatus on this date may therefore be considered fairly trustworthy, and are entirely independent of those made with the hydrometer, Aderman no. 2,

Date	Depth from which the Samples came	Determinations with Tornøe's Apparatus		Determinations with Aderm. no. 2 $S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Difference
		Salinity.	$S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$		
1894. May 30	1600 m.	35·33 ‰	1·02685	1·02668	+ 0·00017
	2000 -	35·22	2678	2669	+ 00009
	2200 -	35·33	2687	2681	+ 00006
	2400 -	34·03	2588	2602	— 00014
				Mean	+ 0·000045

of the same water-samples. The above table gives the differences between the two series of determinations (cf. pp. 210, 211 and 170).

We see that the mean difference is 0·000045, the determinations with the hydrometer being lower than those with Tornøe's apparatus. But as stated on p. 199, it is possible that the salinity of the sample of standard solution had been slightly altered by freezing, and the determinations made with Tornøe's apparatus on this date may thus give somewhat too high values.

As only one determination with the hydrometer was made for each of the first two water-samples, two determinations of the sample from 2200 m. and six determinations of the sample from 2400 m., we can hardly expect a better agreement between the determinations made by the two methods.

The following table gives the differences between Tornøe's determinations of the specific gravity of the five water-samples first examined by him, as mentioned on pp. 212—214, and Blessing's determinations with the hydrometer, Åderman no. 2, of the same samples (pp. 195, 196). The samples were taken in November and December, 1895.

Depth from which the Samples came	Tornøe $S\frac{17{\cdot}5^\circ\,\text{C.}}{17{\cdot}5^\circ\,\text{C.}}$ found with the Sprengel Pycnometer	Blessing $S\frac{17{\cdot}5^\circ\,\text{C.}}{17{\cdot}5^\circ\,\text{C.}}$ found with the Hydrometer Åderman. no. 2	Difference
150 m.	1·02629	1·02633	— 0·00004
200 -	2654	2655	— 00001
250 -	2664	2657	+ 00001
250 -	—	2666	— 00002
800 -	2673	2670	— 00003
850 -	2674	2660	+ 00014
			Mean + 0·00002

We see that the two series of determinations of these five samples give a mean difference of 0·00002, the determinations with the hydrometer being too low.

The following table gives the differences between Heidenreich's and Blessing's determinations of the four other water-samples brought back.

Depth from which the Samples came	Heidenreich. $S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$ found with the Pycnometer	Blessing. $S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$ found with the Hydrometer	Difference
250 m.	1·02665	1·02657	+ 0·00008
250 -	2665	2666	— 00001
450 -	2681	2673	+ 00008
900 -	2672	2668	+ 00004
1900 -	2640	2630	+ 00010
		Mean,	+ 0·00006

The two series of determinations of these four samples give a mean difference of 0·00006, Blessing's determinations with the hydrometer being too low. But, as before stated (see p. 213), Heidenreich's determinations are not so accurate as tbose of Tornøe. The mean difference between the two series of determinations of all nine water-samples is 0·00004.

Blessing's observations with the hydrometer were made in the following manner, according to his very careful notes and his verbal description. The water-sample was poured into the mended glass cylinder described on p. 143, the hydrometer was carefully wiped and immersed, a thermometer, Casella no. 12327, was immersed, and was hanging in the water during the whole series of observations. After a short time, the hydrometer and the thermometer were read off, and a series of about five independent observations were, as a rule, made of each sample. Between some of the readings, and often before every reading, the hydrometer was lifted out of the water, and the stem, or sometimes the whole instrument, was wiped dry. During the above series of observations, the stem of the hydrometer was wiped between the readings (see pp. 195, 196). Before each reading, Blessing generally tapped the outside of the glass cylinder a little, in order to ascertain that the hydrometer had found its natural equilibrium.

According to this method of observing, we might expect Blessing's determinations to have a slight tendency to give somewhat high values, for he had his thermometer hanging in the water during the observations, and did not increase the surface-tension of the water by immersing and removing

it after each reading (see Memoir X, p. 22, etc.). Moreover, he generally wiped merely the stem of the hydrometer, and thus its wet body, when it was again immersed, would tend to diminish the surface-tension of the water, increasing the indication of the hydrometer (see Memoir X, p. 38). On the other hand, his tapping the outside of the glass cylinder before the readings may have reduced the indications a little (see Memoir X, p. 21), but not much, as he tapped quite gently.

The result of the above three series of comparisons is consequently, that our determinations of $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$ with the hydrometers, during the expedition, were,

in July and October, 1893	0·000004 too high
in May, 1894	0·000045 too low
in November and December, 1895 . .	0·000040 too low
Mean,	0·000027 too low,

as compared with the results obtained independently by determinations by other methods.

This may be considered to be in very fair accordance, and may seem to indicate that our determinations of the specific gravities are, if anything, on the whole a trifle too low.

All our determinations of water-samples from depths below 250 metres in the North Polar Basin seem, however, to give very high salinities, or specific gravities, if compared with the salinities observed in the water of the Gulf Stream west of Spitzbergen, or even west of Norway. The salinity of the water in depths below 1000 m. appears also to be considerably higher in the North Polar Basin than in the Norwegian Sea.

In August, 1896, Prof. Arrhenius took a section of the Gulf Stream in about 79° N. Lat., west of Spitzbergen. His Station IV is apparently very nearly in the centre of the current, but according to O. Pettersson and G. Ekman[1], the salinity of the water from depths between 0 m. and 850 m. at this station, varied between 34·89 ‰ and 35·29 ‰. In depths between 100 m. and 850 m., the salinities were from 35·10 ‰ to 35·29 ‰.

[1] Bihang till K. Svenska Vet.-Akad. Handlingar, vol. 23, Part II, No. 4, Stockholm, 1898, p. 32.

In July, 1897, the salinities of the Gulf Stream seem to have been higher west of Spitzbergen, as the salinity at the sea-surface between 76° 34′ N. Lat. and 79° N. Lat. varied from 34·94 ‰ to 35·20 ‰.[1]

In the autumn of 1898, a section of the same branch of the Gulf Stream west of Spitzbergen was taken by the Nathorst Expedition. The salinity of the water of this current seems then to have been less than in the two previous years. According to kind communications received from Dr. Axel Hamberg, the oceanographer of the expedition, no higher salinity than 35·19 ‰, was found in any depth west of Spitzbergen, and this was only found in one water-sample: otherwise the salinity did not exceed 35·15 ‰.

But we have found the salinity of the water of the North Polar Basin below 250 metres to vary from about 35·00 ‰ to 35·37 ‰. Thus the salinity there should, upon the whole, be higher than that found west of Spitzbergen. This may seem improbable, for the saline and comparatively warm water of the North Polar Basin cannot possibly have any other origin than this branch of the Gulf Stream passing northward to the west and north-west of Spitzbergen. But on the other hand, there is, as we have seen, no probability of the salinities or specific gravities found by our observations being on the whole too high.

It was therefore considered important to have some comparative investigations made of the method of determining the salinity of sea-water (by titration), employed in Otto Pettersson's laboratory in Stockholm, where Arrhenius's and Hamberg's water-samples had been examined, and the method of determining the specific gravity, or salinity, employed in Christiania (by Tornøe, Heidenreich and myself), which had afforded the data for the corrections of the observations made on board the Fram. In order to effect this, Prof. Otto Pettersson proposed that we should examine the same water-samples in both places. Four water-samples were selected, and were first examined by Mr. Hercules Tornøe, with the Sprengel pycnometer, then by Mr. O. N. Heidenreich, who, without knowing Tornøe's results, determined the amount of halogen by gravimetric analysis. The samples were then sent to Prof. Otto Pettersson in Stockholm, and were determined in his laboratory by titration. The results of the determinations were the following:

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[2] See Pettersson and Ekman, l. c., p. 38.

Number of Water-sample.	Christiania.			Stockholm.	Δ between Swedish Titrations and Norwegian Determinations.
	Observer and Method.	Salinity.	Δ between Tornøe and Heidenreich.	Pettersson's Laboratory by Titration.	
		‰	‰	‰	‰
I	Tornøe with pycnometer	32·95			
	Heidenreich by gravimetric analysis of halogen	32·957	— 0·007		
	Mean,	32·95		32·82	— 0·13
II	Tornøe with pycnometer	27·58			
	Heidenreich by gravimetric analysis of halogen	27·577	+ 0·003		
	Mean,	27·58		27·51	— 0·07
III	Tornøe with pycnometer	35·33			
	Heidenreich by gravimetric analysis of halogen	35·311	+ 0·019		
	Mean,	35·32		35·20	— 0·12
IV	Tornøe with pycnometer	36·22			
	Heidenreich by gravimetric analysis of halogen	36·185	+ 0·035		
	Mean,	36·20		36·06	— 0·14
	Mean,		+ 0·013		— 0·115

The salinity of *Water-sample No. IV* was also determined by Prof. Pettersson himself, by gravimetric analysis of the halogen, to be

36·11 ‰; Δ from Norwegian determination = — 0·09 ‰.

For referring the specific gravity found by the pycnometer to salinity *per mille*, Tornøe used the factor 1315, which he has found to be the most correct.[1] For finding the salinity from the quantity of halogen, Heidenreich used the factor 1·81, and Pettersson 1·809. If Pettersson had used the same factor as Heidenreich, 1·81, it would have made the Swedish values of the salinity about 0·02 ‰ higher, and the mean differences between the Swedish and the Norwegian determinations would then have been — 0·10 ‰.

[1] See Hercules Tornøe, Nyt Magazin for Naturvidenskaberne, Christiania 1893, (Reprint p. 5).

For the sake of comparison, I may also mention that I have determined the same water-samples with the hydrometer Åderman No. 2, and using the minimum indications of each series of observations, and the maximum correction of the instrument, varying from + 0·00080, at indications of about 1·028, to 0·00085 at indications of about 1·021 (see pp. 148, 150). I find the following specific gravities and salinities of the four water-samples:

Number of Wat.-Samp.	Minimum Reading reduced to 17·5° C.	Error of Instrument.	$S\frac{17{\cdot}5^\circ C}{17{\cdot}5^\circ C.}$	Salinity.	Tornøe's Determinations. Salinity.	⊿ between Tornøe and Nansen.
				‰	‰	‰
I	1·02423	+ 0·00082	1·02505	32·94	32·95	— 0·01
II	1·02010	+ 0·00085	1·02095	27·55	27·58	— 0·03
III	1·02606 [1]	+ 0·00081	1·02687	35·33	35·33	0·00
III	1·02606 [2]	+ 0·00081	1·02687	35·33	35·33	0·00
IV	1·02677 [3]	+ 0·00081	1·02758	36·26	36·22	+ 0·04
					Mean,	0·00

The factor 1315 is used for referring the specific gravity to salinity ‰. The accordance between my determinations with the hydrometer, and Tornøe's determinations with the pycnometer, is good, especially considering that I had taken no special care to secure the highest possible degree of accuracy by means of minimum indications of the hydrometer, because I did not, at that time, know how to do so.

Not being satisfied with the Swedish results, and having discovered that the assistant who had made the titrations had made some slight mistakes, Prof. Otto Pettersson now had a new series of determinations made of three of the above water-samples by the same chemists who had examined the water-samples of Arrhenius and Hamberg from Spitzbergen. This time Pettersson did not have the quantity of halogen determined by titration, but

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[1] This determination was made on October 5th, 1897.

[2] This determination was made a year later, of the same water-sample, on October 26th, 1898.

[3] This determination was made in September, 1897, and I do not feel quite certain that this is exactly the same water-sample that was determined by Tornøe, and sent to Pettersson more than a year later.

by gravimetric analysis. The factor 1·81 was used for calculating the salinity from the quantity of halogen, the results being as follows:

Number of Water-Sample.	Observer.	Halogen.	Salinity.	Norwegian Determinations.	⊿ between Norw. and Swed. Determinations.
		‰	‰	‰	‰
I	A. Cleve	18·172	32·891		
	A. Cleve	18·178	32·902		
			32·897	32·95	+ 0·053
II	O. Pettersson	19·506	35·306	35·32	+ 0·014
IV	G. Forsberg	19·975	36·155		
	G. Forsberg	19·966	36·138		
			36·147	36·20	+ 0·053
				Mean,	+ 0·040

We see that the Swedish determinations are still a little lower, on an average 0·04 ‰, than the Norwegian ones; and if the Swedes had used their usual factor 1·809, instead of 1·81, the difference would have been about 0·06 ‰. We have not yet found out the causes of this difference[1]. It may be that either the factor used by Tornøe (1315) for referring specific gravity to salinity, or that used by the Swedes (1·809, or 1·81) for referring quantity of halogen to salinity, is not quite correct. But however this may be, we have to remember that the salinities obtained by Tornøe's determinations with the pycnometer are, as a rule, about 0·07 ‰ (or 0·05 ‰ if the factor 1·81 be used) higher than the salinities obtained by gravimetric analysis of the halogen at Stockholm. Tornøe's determinations gave salinities which were, on the average, 0·13 ‰ higher than the salinities obtained there by titration (or 0·11 ‰ higher, if the factor 1·81 be used).

As the determinations of the errors of my hydrometers are based upon pycnometer-determinations of the specific gravity of the water-samples, made chiefly by Tornøe, in a few cases also by myself, we may expect that the

[1] According to a letter from Dr. Hamberg, I see that the Swedish weights were not reduced to vacuo. This, however, was always done in Tornøe's determinations with the Sprengel pycnometer.

results of my observations with the hydrometers are, on the whole, relatively somewhat higher, — about 0·10 ‰ — than the results of the Swedish determinations by titration. But on the other hand it should also be remembered that for fear of obtaining too high salinities in the North Polar Basin, I have used the lowest possible corrections for my hydrometer, which may be about 0·00006 too low (see p. 150), corresponding to about 0·08 ‰ of salinity.

Otto Pettersson states that "the salinity of a water-sample can be determined exactly to 0·02 or 0·03 ‰ by a simple titrimetric analysis of the chlorine in the water".[1] I quite agree that such may be the case under favorable circumstances, and when the investigator has had special practice (cf. p. 197, footnote 2); but considering that even the results obtained by the methods of gravimetric analysis of chlorine (halogen) may differ as much as 0·037 ‰, with such skilful investigators as Pettersson and his assistants, I think the probability is that the accuracy attained by titration will in many cases be lower.

In order to acquire fuller knowledge of the relation between the results obtained by titration on the one side, and by the hydrometer and pycnometer on the other, I had two water-samples, taken at Drøbak on April 19th and 20th, 1899, examined by titration by Dr. Hjort's chemical assistant, Mr. S. Schmidt-Nielsen. The same water-samples were determined by Mr. Hercules Tornøe with the Sprengel pycnometer, and by myself with the Sprengel pycnometer as well as with the floating hydrometer and hydrometer of total immersion. The results were the following:

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[1] Otto Pettersson, The Scottish Geographical Magazine, June, 1894, p. 298.

Number of Wat.-sample.	Observer.	$S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$	Salinity *per mille.*	Schmidt-Nielsen by Titration. [1]		Difference.
				Cl. *per litre.*	Salinity.	
			‰		‰	‰
No. I	Tornøe with pycnometer	1·02554				
	Nansen with pycnometer	1·02553				
	Nansen with hydrometer of total immersion	1·02553				
	Nansen with floating hydrometer	1·02553				
	Mean,	1·02553	33·57	18·97 gr.	33·49	— 0·08
No. II	Tornøe with hydrometer	1·02654? [2]				
	Nansen with pycnometer	1·02652? [2]				
	Nansen with hydrometer of total immersion	1·02649				
	Nansen with floating hydrometer	1·02649				
	Mean,	1·02651	34·86	19·68 gr.	34·71	— 1·15

We see that in these cases also, the titrations give lower salinities than the pycnometer, the difference in one case being as much as — 0·15 ‰. Even if we suppose that in the second water-sample, the determinations with the pycnometer by Tornøe and myself are not quite accurate, as they were made somewhat rapidly, it is still certain that the specific gravity has not been lower than that obtained by the hydrometer of total immersion; but this will give a difference of 0·11 ‰ between Schmidt-Nielsen's result and mine.

For the sake of comparison, I will also give here the results of the determinations made in November, 1898, of five water-samples — by Tornøe,

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[1] The solution of nitrate of silver was tested by 'Standard-water of 1899' received from Prof. Otto Pettersson; the calculation of the salinity ‰ was made according to tables written by Prof. Otto Pettersson.

[2] These two determinations are not very accurate, as no second determinations were made for the purpose of control.

with the Sprengel pycnometer, and by Heidenreich by gravimetric analysis of the halogen. The samples are some of those taken by Blessing in November and December, 1895 (see pp. 211—214).

Depth from which Wat.-Samp. came.	Determ. by Heidenreich. Salinity.	Determ. by Tornøe. Salinity.	Difference.
	‰	‰	‰
150 m.	34·479	34·57	+ 0·091
200 -	34·829	34·90	+ 0·071
250 -	34·971	35·03	+ 0·059
800 -	35·114	35·15	+ 0·036
850 -	35·102	35·16	+ 0·058
		Mean,	+ 0·063

If the specific gravities found by Tornøe had been multiplied by the factor 1313 instead of 1315 (salinity ‰ = 1313 $[S\,\frac{17{\cdot}5^\circ\,\text{C.}}{17{\cdot}5^\circ\,\text{C.}} - 1]$) his salinities would have been about 0·053 ‰ lower, and the difference between them and Heidenreich's salinities would have been + 0·01 ‰ instead of + 0·063 ‰. But if Heidenreich had used the same factor as the Swedes, *i. e.* 1·809 instead of 1·81, the difference between his and Tornøe's salinities would have been about + 0·08 ‰. If the factor 1312 had been used for reducing Tornøe's specific gravities, the difference between the salinities found would then have been only + 0·002 ‰, Heidenreich's being lower.

The result of the above comparison agrees well with what was found before; the salinity calculated from the quantity of halogen by the Swedish factor 1·809 is about 0·08 ‰ (or as in the previous case 0·07 ‰ — see p. 230) lower than that found from the specific gravity according to Tornøe's formula, $1315\,(S\,\frac{17{\cdot}5^\circ\,\text{C.}}{17{\cdot}5^\circ\,\text{C.}} - 1)$.

PART 3.

THE CIRCULATION OF THE NORTH POLAR BASIN.

I.

THE FINAL VALUES OF THE TEMPERATURE, SALINITY, AND DENSITY OF THE WATER OF THE BARENTS SEA AND THE NORTH POLAR BASIN, ACCORDING TO OUR DETERMINATIONS.

After Part 1 of this Memoir had been printed, the missing Negretti and Zambra reversing thermometer No. 75684 (see pp. 53—56) was found in one of the cases from the Fram Expedition in my possession. In October, 1900, I found its zero-correction to be — 0·175° C., being the mean of several determinations varying between — 0·18° C. and — 0·17° C. This result seems to agree well with the correction assumed for this instrument, which was — 0·16° C. for November, 1895 (see p. 56).

If the broken-off column of mercury in the instrument indicates temperatures about zero, its expansion or contraction will, according to my determinations, cause an error of **0·014°** C. for each degree Centigrade by which the temperature at which the thermometer is read off differs from the reading.

This explains why such great zero-corrections were found on board the Fram for the Negretti and Zambra reversing thermometers: see footnotes on pp. 53, 56, and 58. As the available quantity of hoar-frost used for testing the zero was generally very small, only one end of the thermometer could be immersed to assume the zero temperature, while the other end would be very nearly at the temperature of the cabin, which was generally about 20° C. The broken-off column of mercury would consequently assume the same temperature, which would cause an error in the reading of about 0·28° C., which the thermometer would indicate too high. If the correc-

tions observed on May 14th, 1895, and February 5th, 1896 (see pp. 53, 58) are corrected for this error, we find for the N. Z. thermometer No. 75682 a zero-correction of $-0{\cdot}40^0 + 0{\cdot}28^0 = -\mathbf{0{\cdot}12}^0$ C. for May, 1895. We found before (on p. 52) a correction of $-0{\cdot}13^0$ C. as probable for this month.

For the N. Z. thermometer No. 75680, we find in the same manner a correction of $-0{\cdot}40^0$ C. $+ 0{\cdot}28^0$ C. $= -\mathbf{0{\cdot}12}^0$ C. for February, 1896. This correction seems to be somewhat great.[1] We found before (see p. 58) a probable correction of $-0{\cdot}06^0$ C. for this thermometer.

The zero-correction observed for the N. Z. thermometer No. 75684, on May 28th, 1895, cannot, however, be corrected in the same manner, as this thermometer was enclosed in the brass cylinder of the turning apparatus (see footnote, p. 56) during the determination. It has evidently been necessary in this case to collect more hoar-frost, so that the whole brass cylinder could be more or less immersed during the observation. The result is that we have in this case obtained a smaller and more probable correction, although it also is evidently somewhat too great.

In my discussion of the errors of the thermometers in Part 1, I say on p. 43: 'If the thermometers, for some time before they are read, are exposed to air which is very much colder than the water, the contraction of the broken-off column of mercury might easily cause a considerable error. As our thermometers, however, were always read as soon as they came out of the water, no significant error can have been caused in this way,' etc. By now making experiments with the thermometer formerly missing, I find that this assumption is hardly correct.

If the thermometer be read off in air with a temperature differing much from that of the water, a delay of a few minutes before the reading is taken is sufficient to cause appreciable errors in the reading. The thermometer, enclosed in a brass tube similar to that of the reversing apparatus used on board the Fram, was placed in melting ice and reversed, and was afterwards read off at intervals, hanging in air with a temperature of $18{\cdot}9^0$ C. The increase of the indication of the broken-off column of mercury was,

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[1] By keeping the thermometer in the hand (see Blessing's note, in footnote on p. 58), the temperature of the broken-off column of mercury might have been raised more than has been assumed above. Appreciable errors may also be caused by taking the thermometer out of the melting hoar-frost before it is turned.

After	2	minutes	in	the	air,	0·01°	C.		
„	3	—	—	„	0·03	„			
„	5	—	—	„	0·07	„			
„	6	—	—	„	0·10	„			
After	10	minutes	in	the	air,	0·15°	C.		
„	12	—	—	„	0·17	„			
„	15	—	—	„	0·22	„			

We thus see that a few minutes in the air might be sufficient to change the reading appreciably, if the temperature of the air differs as much as 19° C. from that of the water. It sometimes happened during the observations on our expedition, that the temperature of the air was as much as 30° C., or more, lower than the temperature of the water. If the temperature of the air be higher than that of the water, the heating of the thermometer will be retarded by the evaporation of water from the wet surface of the instrument, engaging heat; but if the temperature of the air be colder, the cooling will also be retarded by the freezing of water on the wet surface of the instrument, disengaging heat.

According to the above statement, we must expect the temperature-readings of the sea-water taken with the reversing thermometers on cold days during the expedition to have a tendency to be somewhat too low, as some interval of time would naturally always pass before the reading could be taken with a lens and often with a lantern, after the thermometer came up.

The inaccuracy thus arising was, however, to some extent checked by the simultaneous observations of the water-temperature made with Pettersson's insulated water-bottle, by which the corrections of the reversing thermometers were determined on the various dates. On pp. 8 to 10, I mention, however, several reasons why the temperature-readings taken by insertion of a cold thermometer in the water-bottle might have been too low on cold days, but I did not expect the errors thus caused "ever to be more than 0·04° C. or say 0·05° C., at most, in our series of water-temperatures". At my request, Mr. Helland-Hansen, of the Norwegian Oceanic Survey, has now kindly made experiments on this point with a water-bottle of exactly the same construction as ours; and I find that according to his results, the errors caused by the higher or lower air-temperature may be greater than I expected.

Helland-Hansen's experiment was as follows. The water-bottle was left hanging in an aquarium of the marine biological station at Bergen, for 15 minutes before it was closed, and the temperature of the water was determined to be 6·88° C. The water-bottle was now carried into the laboratory, where the air had a temperature of about 21° C. A thermometer, similar to our

Müller Nos. 6 and 7, was inserted in the water-bottle, and the following readings were taken,

After	3	minutes,	7·03° C.	After	6½	minutes,	6·95° C.
„	4	—	6·96 „	„	8	—	6·95 „
„	5	—	6·94 „	„	10	—	6·97 „

The temperature-readings are corrected for instrumental error. We see that the thermometer needed 5 minutes to assume its lowest reading of 6·94° C., but even this is 0·06° C. higher than the original temperature of the water. This was when the difference in temperature between the water and the air was about 14° C. (21° C.—6·88° C.). The error caused by each degree Centigrade by which these two temperatures differ, should consequently be 0·06:14 = **0·0043**° C. If the temperature of the air be — 30°, and the temperature-reading of the water-bottle be about 0° C., an error of 30 × 0·0043 = 0·13° C. would thus be caused in our determination of the water-temperature.

Our temperatures taken with Pettersson's insulated water-bottle during the expedition, ought therefore to be revised and corrected for the errors thus caused, by the above coefficient 0·0043° C. for each degree; this will give the following corrections for our several series of deep-sea temperatures.

Table 1. Corrections for Temperature-Readings taken with the Insulated Water-Bottle, for errors caused by the Temperature of the Air.

Difference in *t* between Wat.-Samp. and Air.	Correction.	Difference in *t* between Wat.-Samp. and Air.	Correction.
° C.	° C.	° C.	° C.
+ 2	— 0·01	— 16	+ 0·07
0	0·00	— 18	+ 0·08
— 2	+ 0·01	— 20	+ 0·09
— 4	+ 0·02	— 22	+ 0·09
— 6	+ 0·03	— 24	+ 0·10
— 8	+ 0·03	— 26	+ 0·11
— 10	+ 0·04	— 28	+ 0·12
— 12	+ 0·05	— 30	+ 0·13
— 14	+ 0·06	— 32	+ 0·14

The errors of the Negretti and Zambra reversing thermometers on the various dates have been determined by the simultaneous observations made with the insulated water-bottle (see pp. 45, 54). The corrections for the observations made with these instruments will therefore have to be changed accordingly.

After having corrected my several temperature-series according to the above table, and considering only observations from depths of less than 120 m., or in some few cases (October and November, 1894) even 150 m., I thus find the following corrections for the Negretti and Zambra reversing thermometers Nos. 75682 and 75684, which should be used instead of those given on pp. 52 and 56,[1] and applied in the Table on pp. 108 *et seq.*

Table 2. Corrections for N. Z. Nos. 75682 and 75684.

Date.	Correction.	Date.	Correction.
	° C.		° C.
April 1894	— 0·06	Nov. 1894	— 0·03
May „	— 0·07	May 1895	— 0·10
June „	— 0·05[2]	July „	— 0·10
August „	— 0·05	Nov. „	— 0·10
October „	— 0·05		

If the temperature-reading of the reversing thermometer differs as much as 0·5° C. or more from the temperature of the upper strata of the sea, *i. e.* the strata above 100 m., we have also to consider the correction caused by the contraction of the broken-off column of mercury at the lower temperature — about — 1·6° C. or — 1·5° C. — which the thermometer must have assumed while passing up through the cold, upper water-strata. This correction, as stated above (on p. 237) is + 0·014° C. for each degree Centigrade lower temperature, and will give the following table of Corrections.

[1] The correction of N. Z. reversing thermometer No. 75680 will remain the same as given on p. 58.

[2] I have here taken the mean of all observations made on the several dates of June, 1894, for depths of less than 120 m.

Table 3. Corrections for Readings of Negretti and Zambra reversing Thermometers.

Difference between *t in situ* and *t* of the upper Water-Strata.	Correction.	Difference between *t in situ* and *t* of the upper Water-Strata.	Correction.
° C.	° C.	° C.	° C.
— 0·5	+ 0·01	— 1·75	+ 0·02
— 0·75	+ 0·01	— 2·0	+ 0·03
— 1·0	+ 0·01	— 2·25	+ 0·03
— 1·25	+ 0·02	— 2·5	+ 0·04
— 1·5	+ 0·02	— 3·0	+ 0·04

I have had all observations in our several series of deep-sea temperatures revised and corrected for the errors given in the three tables above. All temperatures obtained with the insulated water-bottle, and given in the twelfth column of the table on pp. 108 *et seq.*, were corrected according to Table 1 above; the uncorrected temperature-readings of the N. Z. reversing thermometers (see the ninth column of the Table on pp. 108 *et seq.*) were corrected by the new corrections given in Table 2 above, and those from the deeper and warmer strata also, by the corrections given in Table 3 above.

The correct temperatures of the water *in situ* thus obtained are given in the following table of the final results of our deep-sea observations. Where there are several observations for the same depth, the mean of these observations is given, as a rule.

In the following table are also given the final values of the salinities and specific gravities ($S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$) of the sea as found by our observations (see table, pp. 166 *et seq.*). For water-samples that have been determined both with Tornøe's apparatus and with the hydrometers, from July, 1893, to the end of May, 1895 (see table pp. 201 *et seq.*), the mean of these observations is given, when not otherwise stated.

The density ($S\frac{t}{4^\circ\,C.}$) of the sea-water *in situ* has been calculated from the specific gravities, $S\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.}$, by Makaroff's table in his work, 'Le Vitiaz et l'Océan Pacifique,' p. 123. The compression of the water by the pressure of the overlying water-strata has not been allowed for.

TABLE.

The columns in the following table give,

First column. The Distinguishing number of the Series of Soundings; see Tables pp. 108 *et seq.*, and pp. 166 *et seq.*

Second column. The Date when the Water-Sample was taken. Under the Dates are given, first, the North Latitude (marked N), and beneath it the Longitude East of Greenwich (marked E).

Third column. The Depth in Metres from which the Water-Sample came.

Fourth column. The same Depth in English Fathoms.

} A thick line under the number indicates Bottom.

Fifth column. The correct Temperature of the Sea-Water *in situ:* cf. what is said above.

Sixth column. The specific Gravity, $S\frac{17{\cdot}5^{\circ}\,\mathrm{C.}}{17{\cdot}5^{\circ}\,\mathrm{C.}}$, of the Water-Samples. Where determinations are made both with Tornøe's Apparatus and with the Hydrometer (from July, 1893, to May, 1894), the mean Salinity given by the observations has been referred to Specific Gravity by the coefficient 1315.

Seventh column. The Salinity *(per mille)* of the Water-Samples, *i. e.* grams of total Salts in one kilogram of Sea-Water.

An *asterisk* before the number given, indicates that the Salinity is found as a mean between the determinations made with the Hydrometer and with Tornøe's Apparatus (see Table pp. 201 *et seq.*). An *asterisk* after the number, indicates that the Salinity is determined with Tornøe's Apparatus only. The Salinities with no *asterisk* are found by determinations with the Hydrometer only, when not otherwise stated.

Eighth column. The Density, $S\frac{t}{4^{\circ}\,\mathrm{C.}}$, of the Sea-Water *in situ.* The calculations are made from the $S\frac{17{\cdot}5^{\circ}\,\mathrm{C.}}{17{\cdot}5^{\circ}\,\mathrm{C.}}$, by Makaroff's Table[1], with no allowance for the compression of the water by the pressure of the overlying water-strata.

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[1] 'Le Vitiaz et l'Océan Pacifique', pp. 123 *et seq.* St. Petersburg, 1894.

TABLE

SHOWING FINAL VALUES OF TEMPERATURE *IN SITU*, SALINITY AND DENSITY OF THE WATER OF THE BARENTS SEA AND THE NORTH POLAR BASIN, 1893—1896.

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ*.	$S\,\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\,\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1893.			° C.		‰		
1	July 22	0	0	5·80	1·02593	34·10	1·02678	
	70° 43′ N	20	11	3·92	2664	35·03	2772	
	39 20 E	40	22	3·58	2664	35·03	2775	
		60	33	1·58	2662	35·01	2789	
		80	44	1·01	2661	34·99	2792	
		100	55	0·65	2661	34·99	2795	
		150	82	−0·61	2752?			
		200	109	−1·14	2674	35·16	2817	
2	July 23	0	0	5·1	1·02624	34·50	1·02719	
	71° 1′ N	20	11	3·68	2634	*34·64	2734	
	43 38 E	40	22	1·34	2646	*34·79	2775	
		60	33	0·54	2648	*34·82	2782	
		80	44	−0·44	2658	*34·96	2797	
		100	55	−0·70	2652	*34·87	2793	
		130	71·5	−0·54	2655	34·91	2795	
3	July 24	0	0	3·69	1·02620	34·46*	1·02729	
	71° 17′ N	20	11	2·91	2625	*34·52	2741	
	48 22 E	40	22	−1·32	2652	34·87*	2795	
		60	33	−1·64	2612?	34·35?*	2754?	
		80	44	−1·72	2662	*35·00	2807	
		100	55	−1·63	2655	34·92*	2799	
		120	66	[−1·63]	2665	35·05*	2810	
		130	71·5					
3a	July 25							
	71° 22′ N	126·5	69	[−1·63]	1·02664	35·04*	1·02809	
	50 6 E							
4	July 25	0	0	6·92	1·02371	31·18*	1·02437	
	71° 23′ N	10	5·5	3·85	2549	33·52*	2653	
	51 36 E	20	11	1·94	2605	34·26*	2728	
		30	16·4	0·87	2602	34·22*	2732	
		40	22	−0·50	2645	34·78*	2784	
		60	33	−1·01	2656	34·93*	2798	
		70	38·5	−1·11	2673	35·15*	2815	

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1893.			° C.		‰		
5	July 27	0	0	8·40	1·01776	*23·36	1·01809	
	69° 43′ N	5	2·7	4·16	2159	*28·39	2249	
	54 23 E	10	5·5	2·11	2309	*30·36	2418	
		12	6·5	0·09				
		13·5	7·4	−0·73				
		14·5	8	−1·25	2586	*34·01	2725	
		15	8·2	−1·51				
		20	11	−1·57	2619	*34·44	2761	
		30	16·4	−1·65	2636	*34·66	2779	
		40	22	−1·57	2638	*34·69	2781	
		50	27·3	−1·55	2639	*34·70	2782	
6	July 28	0	0	1·74	1·00264	3·47*	1·00276	In the ice.
	69° 25′ N	5	2·7	−1·37	2409	31·68	2538	
	57 7 E	10	5·5	−1·56	2585	*33·99	2725	
		15	8	−1·59	2591	*34·07	2731	
		20	11	−1·67	2613	34·36	2755	
		22	12	−1·60				
7	Aug. 11	0	0	−0·22	1·01460	19·19	1·01535	In the ice.
	71° 21′ N	5	2·7	0·32	2314	30·43	2433	
	66 24 E	10	5·5	−0·84	2030	26·68	2139	
		15	8	−1·16	2405	31·63	2533	
		20	11	−1·06	2461	32·36	2592	
		24	13	−1·09	2479	32·60	2611	
		26·5	14·5					
8	Oct. 4	1370	750	−0·40				
	78° 38′ N	1465?	800?	(0·18?)				
	135 0 E							
9	Oct. 9	0	0	−1·6?	1·02183	28·70*	1·02300	
	78° 20′ N	20	11	*−1·45 [1]	2232	*29·35	2351	
	136 0 E	40	22	−1·6?				
		60	33	−1·45				
		80	44	−1·5				
		100	55	*−1·62	2506	32·96*	2641	
		120	66	*−1·38	2565	*33·73	2703	
		145	79	*−1·21	2588	*34·04	2727	
10	Oct 12							
	78° 13′ N	90	49·5	−1·4				
	135 55 E							

[1] For depths where determinations of the temperature were made with the insusulated water-bottle, only these are given on this date.
They are marked with an *asterisk*.

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1893.			° C.		‰		
11	Nov. 9 77° 55′ N 137 50 E	0·5 10 20 30 40 51 53	0·3 5·5 11 16·4 22 27·9 29	−1·43 [1] −1·32 −1·37 −1·34 −1·44 −1·54	1·02160 2154 2164 2213 2369 2445	28·40* 28·33* 28·46* 29·10* 31·15* 32·15*	1·02275 2269 2279 2330 2496 2577	[1] Only the determinations of temperature made with the insulated water-bottle are given in the series for this date.
12	Dec. 21 79° 8′ N 137 20 E	1500	820	−0·56?				
	1894.							
13	March 1 80° 0′ N 135 0 E	1850	1012	−0·6?				
14	April 14 80° 12′ N 133 50 E	0 0·5 1 20 40 60	0 0·27 0·55 11 22 33	−1·55 −1·55 [−1·56] −1·59 −1·70 −1·76	— 1·02286 2256 2364 2584 2540	— *30·06 *29·67 *29·77 *31·35 33·40	— 1·02408 2377 2385 2511 2677	
	April 15 80° 11·1′ N 133 31 E	80 100 120 140 160 180 200 230	44 55 66 77 87 98 109 126	−1·74 −1·61 −1·50 −1·25 −0·87 −0·30 −0·22 0·22	1·02575 2602 2622 2639 2577? 2634 2643	*33·86 *34·21 *34·48 *34·70 *33·89? *34·63 *34·76	1·02715 2743 2763 2781 2714? 2772 2781	
	April 23 80° 27·6′ N 131 14 E	250 [1] 300 350 400 500 550 600	137 164 191 219 273 301 328	0·23 0·27 0·25 0·36 0·36 0·19 0·15	1·02667 2669 2678 2678 2681	*35·07 *35·09 *35·22 *35·22 *35·25	1·02803 2806 2815 2815 2818	[1] The temperature and salinity given for this depth are the means of all observations taken on April 15th, 21st, and 23rd, 1894
	April 24 80° 29·1′ N 131 25 E	700 800 900	383 437 492	0·07 −0·03 −0·03	1·02688?	35·35? [2]	1·02827?	[2] Only by determination with hydrometer.

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1894.			° C.		‰		
	April 24	1000	547	−0·12	1·02678	*35·22	1·02817	
	80° 29·1′ N	1100	601	−0·24				
	131 25 E	1200	656	−0·32	2680	*35·24	2820	
		1300	711	−0·42				
		1400	766	−0·42				
	April 26	1400	766	−0·44	1·02683	*35·28	1·02823	
	80° 34·6′ N							
	131 34 E	1500	820	−0·52				
	April 24	1600	874	−0·58	1·02677	*35·21	1·02818	
	April 25	1700	930	−0·66				
	80° 32′ N	1800	984	−0·67	1·02680	*35·24	1·02822	
	131 30 E	1900	1039	−0·73				
		2000	1094	−0·75	2679	35·23*	2821	
		2200	1203	−0·79	2674	*35·16	2816	
		2400	1312	−0·82	2687	*35·33	2829	
15	May 22	0·3	0·16	−1·71	1·02285	30·05	1·02407	
	81° 24′ N	10	5·5	−1·65	2316	*30·46	2440	
	125 0 E	20	11	−1·66	2306	*30·32	2429	
		30	16·4	−1·62				
		40	22	−1·67	2465	*32·42	2598	
		50	27·3	−1·72				
		60	33	−1·73	2559	*33·65	2698	
		70	38·5	−1·71				
		80	44	−1·73	2594	*34·11	2734	
		90	49	−1·67				
		100	55	−1·60	2618	*34·42	2760	
		110	60	−1·53				
		120	66	−1·43	2626	*34·53	2768	
		140	77	−1·41				
		160	87	−1·15	2631	*34·59	2773	
		180	98	−0·54				
		200	109	−0·30	2641	*34·73	2779	
	May 23	220	120	−0·16				
	81° 26·8′ N	240	131	−0·07	1·02688	35·35*	1·02827	
	123 0 E	280	153	0·19				
		300	164	0·19	2675	*35·17	2812	
		400	219	0·35	2675	*35·18	2812	
		500	273	0·34	2672	*35·14	2809	
		550	301	0·20				
		600	328	0·15	2672	*35·13	2809	

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1894.			° C.		‰		
	May 24	650	355	0·14				
	81° 32·6′ N	700	383	0·05	1·02665	*35·04	1·02803	
	123 2 E	750	410	−0·01				
		800	437	−0·04	2678	35·21*	2817	
		850	465	−0·06				
		900	492	−0·08	2684	35·29*	2823	
		950	519	−0·11				
		1000	547	−0·16	2675	*35·18	2815	
		1050	574	−0·27				
		1200	656	−0·32	2687	35·33*	2827	
		1300	711	−0·46				
		1400	766	−0·46	2677	*35·20	2818	
	May 25	1500	820	−0·53				
	81° 31′ N	1600	874	[−0·64]	1·02677	*35·20	1·02818	
	123 2 E	1700	930	−0·66				
		1800	984	−0·69	2676	35·19*	2818	
		1900	1039	−0·70				
		2000	1094	−0·76	2674	*35·16	2916	
		2100	1148	−0·80				
		2200	1203	−0·80	2684	*35·29	2826	
	May 26	2300	1258	−0·84				
	81° 30·6′ N							
	123 0 E							
16	June 26	0·20	0·08	0·34	1·00384	5·05	1·00397	
		5	2·7	−1·60	2268	29·82	2389	
	June 22	10	5·5	−1·62 [1]	2262	29·74	1·02383	[1] These temperatures are means of observations taken on June 22 and 23.
	81° 46′ N	20	11	−1·60 [1]	2277	29·93	2399	
	121 40 E	30 [2]	16·4	−1·60	2293	30·16	2416	[2] By a printer's error in the table of the temperatures on p. 118, June 26 is recorded as the date of the depths from 30 m. to 50 m.; it should be June 22.
		40	22	−1·62	2463	32·39	2596	
		50	27·3	−1·71	2541	33·41	2678	
		60	33	−1·76 [1]	2571	33·81	2710	
	June 23	80	44	−1·69	1·02589	34·05	1·02729	
	81° 41·7′ N	100	55	−1·58	2630	34·58	2773	
	121 30 E	120	66	−1·32	2622	34·47	2763	
	June 25	140	77	−0·97	1·02631	34·60	1·02772	
	81° 39·2′ N	160	87	−0·68	2640	34·72	2780	
	121 30 E	180	98	−0·35	2646	34·79	2785	

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^\circ\ C}{17{\cdot}5^\circ\ C.}$	Salinity.	$S\frac{t}{4^\circ\ C.}$	Remarks.
	1894.			° C.		‰		
	June 25	200	109	−0·27	1·02660	34·98	1·02799	
	81° 37′ N	225	124	−0·05	2658	34·95	2796	
	121 0 E	250	137	0·49	2678	35·22	2814	
		275	150	0·29	2680	35·24	2817	
		300	164	0·53	2672	35·14	2808	
	June 26	310	170	0·57	2674	35·16	2809	
	June 25	325	178	0·55	2677	35·20	2812	
	June 26	325	178	0·32				
	81° 37′ N	350	191	0·36	1·02678	35·22	1·02815	
	121 6 E	375	205	0·37	2672	35·14	2809	
		400	219	0·38	2675	35·18	2812	
		425	232	0·39	2678	35·22	2815	
		450	246	0·40	2681	35·26	2818	
		500	273	0·30	2683	35·28	2820	
		550	301	0·26	2679	35·23	2816	
		600	328	0·18	2687	35·33	2825	
		700	383	0·13	2677	35·20	2815	
	June 27	800	437	0·01	1·02669	35·10	1·02807	
	81° 36′ N	1000	547	−0·11	2670	35·11	2809	
	121 12 E	1200	656	−0·34	2665	35·04	2804	
		1400	766	−0·44				
		1600	874	−0·58	2670	35·11	2809	
16a	June 26	225	123	−0·05				
	81° 37′ N	250	137	0·16				
	121 6 E	275	150	0·19				
		280	153	0·16				
		290	159	0·55				
		300	164	0·54				
		310	170	0·57	1·02674	35·16	1·02809	
		325	178	0·55				
16b	June 27	225	123	0·02				
	81° 36′ N	250	137	0·30				
	121 12 E	275	150	0·25				
		300	164	0·35				
		325	178	0·39				
		350	191	0·38				
17	July 11	0·05	0·03	[0·18]	1·00094	1·24	1·00089	
	81° 18·9′ N	0·12	0·07	0·18	0106	1·36	0101	
	124 38 E	1	0·55	0·14	0091	1·20	0086	
		2	1·09	0·08	0169	2·22	0192	

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1894.			° C.		‰		
	July 11	3	1·64	−1·59	1·02217	29·16	1·02335	
	81° 18·9′ N	5	2·73	−1·63	2258	29·69	2379	
	124 38 E	10	5·47	−1·62	2248	29·56	2369	
18	Aug. 13	0	0	0·80				
	81° 44′ N	1	0·55	0·65				
	127 55 E	1·6	0·88	0·07				
		1·65	0·91	−0·38				
		2	1·09	−1·40				
		2·5	1·37	−1·36				
		3	1·64	−1·46				
		5	2·73	−1·55				
		10	5·47	−1·55				
		20	11	−1·55				
		30	16·4	−1·60				
		40	22	−1·72				
		50	27·3	−1·75				
		60	33	−1·72				
		80	44	−1·72				
		100	55	−1·62				
		120	66	−1·47				
		140	77	−1·19				
		160	87	−0·80				
		180	98	−0·52				
		200	109	−0·23				
		220	120	0·00				
		240	131	0·01				
		260	142	0·16				
		280	153	0·25				
		300	164	0·18				
	Aug. 14	300	164	0·25				
	Aug. 13	325	178	0·33				
		350	191	0·29				
	Aug. 14	350	191	0·27				
	81° 5·6′ N	375	205	0·27				
	127 57 E	400	219	0·32				
	Aug. 14	450	246	0·32				
	81° 5·6′ N	500	273	0·30				
	127 57 E	550	301	0·19				
		600	328	0·16				
		650	355	0·14				
		700	383	0·10				

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ*.	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1894.			° C.		‰		
	81° 5·6′ N 127 57 E	800	437	0·02				
		900	492	−0·09				
		1000	547	−0·14				
	Aug. 15 81° 6·6′ N 127 49 E	1200	656	−0·32				
		1300	711	−0·34				
		1400	766	−0·38				
		1500	820	−0·48				
		1600	874	−0·50				
		1700	930	−0·61				
		1800	984	−0·65				
		1900	1039	−0·69				
	Aug. 16 81° 6′ N 128 0 E	2100	1148	−0·73				
		2600	1422	−0·79				
		2900	1586	−0·81				
		3000	1640	−0·78				
	Aug. 17 81° 6′ N 128 0 E	3400	1859	−0·74				
		3700	2023	−0·70				
		3800	2078	−0·69				
19	Oct. 22 82° 1′ N 114 40 E	0	0	−0·16				
	Oct. 18	5	2·73	−1·55	1·02274	29·90	1·02394	
	Oct. 17 81° 43·5′ N 125 40 E	50	27·3	−1·78	1·02563	33·70	1·02702	
		150	82	−0·47	2646	34·79	2785	
		200	109	0·61	2677	35·20	2812	
		250	137	0·74	2669	35·10	2803	
		300	164	0·79	2676	35·19	2810	
	Oct. 18 81° 48′ N 115 30 E	350	191	0·74	1·02679	35·23	1·02814	
		400	219	0·76	2686	35·32	2820	
		450	246	0·72	2689	35·36	2824	
		500	273	0·60	2683	35·28	2818	
		600	328	0·33	2671	35·12	2808	
		700	383	0·11	2680	35·24	2818	
	Oct. 19 81° 55′ N 115 8 E	800	437	0·06	1·02681	35·26	1·02819	
		1000	547	−0·25				

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ*.	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1894.			° C.		‰		
	Oct. 20 82° 0′ N 114 51 E	1500 2000	820 1094	−0·62 −0·86	1·02680	35·24	1·02821	
	Oct. 27 82° 4′ N 114 35 E	2500	1367	−1·18?[1] [−0·89]	1·02691	35·39	1·02836	
	Oct. 29 82° 11′ N 113 13 E	3000	1640	−0·84	1·02682	35·27	1·02824	
20	Nov. 3 82° 6′ N 111 30 E	0 0·5 1 2 3 10 25 50	0 0·27 0·55 1·09 1·64 5·5 13·7 27·3	−0·24 −0·20 −0·25 −1·56 −1·57 −1·56 −1·63 −1·72	1·00342 2291 2290 2298 2571	4·50 30·12 30·11 30·22 33·81	1·00376 2414 2413 2421 2710	
	Nov 2 82° 6′ N 111 30 E	75 100 125 150 200 250 310 350 400	41 55 68 82 109 137 170 191 219	−1·77 −1·65 −1·05 −0·42 0·67 0·72 0·78 0·69 0·69	1·02621 2674 2669 2675 2668	34·47 35·16 35·10 35·18 35·08	1·02763 2809 2803 2810 2803	
	Nov. 3 82° 6′ N 111 30 E	600 700 1000	328 383 547	[0·21] [−0·13] −0·23	1·02677 2666 2677	35·20 35·06 35·20	1·02814 2805 2815	
	1895.							
21	April 6 84° 18′ N 96 40 E	0 5	0 2·73	−1·78 −1·73	1·02357 2369	31·00 31·15	1·02484 2496	

[1] This temperature is evidently too low. The probability is that the N. Z. reversing thermometer had been hanging too long in the air before the reading was taken, and the broken-off mercury had thus assumed very nearly the temperature of the air, which was − 33° C. The reading of the thermometer was −1·24° C., its instrumental correction was probably about −0·10° C., and the correction caused by the low air-temperature has been +0·45, which give a correct temperature *in situ* of −0·89° C.

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17.5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
22	1895.			° C.		‰		
	May 13	0	0	−1·70	1·02437	32·05	1·02568	
	May 20	1	0·55	−1·74				
	84° 33′ N	2	1·09	−1·69				
	85 18 E	3	1·64	−1·69				
		4	2·19	−1·69				
	May 13 [1]	10	5·5	−1·79	1·02380	31·30	1·02508	[1] The temperatures andthe water-samples were not taken simultaneously during this series in May, 1895.
	84° 39′ N	20	11	−1·77	2463	32·39	2596	
	88 30 E	30	16·4	−1·80				
		40	22	−1·90	2527	33·23	2664	
		50	27·3	−1·90				
		60	33	−1·89	2578	33·90	2718	
		80	44	−1·87	2597	34·15	2738	
		100	55	−1·88	2605	34·26	2746	
		120	66	−1·50				
		140	77	−0·84				
		150	82	[−0·47]	2636	34·66	2775	
		160	87	−0·10				
		180	98	0·33				
		200	109	0·78	2652	34·87	2786	
	May 14	225	123	0·79				
	84° 39′ N	250	137	1·09	1·02670	35·11	1·02802	
	88 16 E							
	May 15	275	150	1·09				
	84° 38′ N	300	164	1·04	1·02672	35·14	1·02804	
	88 0 E	325	178	1·13				
		350	191	1·08	2678	35·22	2810	
		400	219	0·87	2675	35·18	2809	
	May 16	450	246	0·74	1·02674	35·16	1·02809	
	84° 37′ N	500	273	0·64	2672	35·14	2807	
	87 45 E	550	301	0·54	2674	35·16	2810	
		600	328	0·58	2679	35·23	2814	
		650	355	0·38	2681	35·26	2818	
		700	383	0·28	2679	35·23	2816	
		746	408	0·13	2676	35·19	2814	
	May 22	800	437	0·08	1·02685	35·31	1·02823	
	84° 40′ N	850	465	−0·03				
	83 51 E							
	May 24	900	492	−0·02	1·02671	35·12	1·02810	
	84° 41·4′ N	1000	547	−0·23	2675	35·18	2815	
	82 24 E							

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1895.			° C.		‰		
	May 25 84° 40′ N 82 15 E	1100 1200	602 656	−0·28 −0·40	1·02679 2680	35·23 35·24	1·02819 2820	
23	July 31	0	0	0·16	1·02408	31·66	1·02532	
	July 20 July 27	0·5	0·27	−0·02				
	July 20 84° 39′ N 73 30 E	0·75 1	0·41 0·55	−0·37 −1·16				
	July 27 84° 29′ N 73 25 E	1·25 1·5	0·68 0·82	−1·65 −1·69				
	July 20	2 3	1·09 1·64	−1·69 −1·68				
	July 27 July 20 July 27	4	2·19	−1·66				
	July 31 84° 28·1′ N 75 56 E	20 40 60 80 100 120 140	11 22 33 44 55 66 77	−1·79 −1·88 −1·88 −1·86 −1·78 −1·59 −1·48	1·02457 2545 2574 2599 2613 2619 2621	33·31 33·47 33·85 34·18 34·36 34·44 34·47	1·02590 2683 2713 2740 2755 2761 2762	
	July 29 84° 32′ N 73 55 E	160 180 200 250 300 350 400 500 600	87 98 109 137 164 191 219 273 328	−0·82 0·12 0·43 1·04 1·18 1·19 0·99 0·73 0·56	1·02647 2649 2660 2673 2674 2674 2672 2678 2677	34·81 34·83 34·98 35·15 35·16 35·16 35·14 35·22 35·20	1·02787 2786 2796 2805 2805 2805 2805 2813 2813	
	July 30 84° 33·6′ N 74 17 E	700	383	0·47	1·02677	35·20	1·02814	
	July 31 84° 28·1′ N 75 56 E	800 850 900 950	437 465 492 519	0·12 −0·02 −0·04 −0·11	1·02679 2681 2667 2676	35·23 35·26 35·07 35·19	1·02817 2820 2806 2815	

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1895.			° C.		0/00		
	July 25	1000	547	−0·33	1·02691	35·39	1·02832	
		1100	601	−0·44	2693	35·41	2835	
		1200	656	−0·49	2683	35·28	2824	
		1300	711	−0·59	2677	35·20	2818	
	July 26	1400	766	−0·73	1·02680	35·24	1·02822	
		1500	820	−0·76	2673	35·15	2815	
		1600	875	−0·64	2679	35·23	2821	
		1700	930	−0·79	2675	35·18	2817	
24	Dec. 9 85° 25′ N 53 47 E	0	0	−1·69				
	Nov. 12 85° 52′ N 66 11 E Dec. 9	1 5 5	0·55 2·73 2·73	−1·70 −1·70 −1·69				
	Nov. 30 85° 28·6′ N 58 41 E	150 200 250	82 109 137	−1·35 0·11 0·57	1·02629[1] 2654[1] 2665[2]	34·57 34·90 35·04	1·02771 2791 2800	[1] Determinations by Tornøe with pycnometer. [2] Mean of determinations of two samples, by Tornøe and Heidenreich.
	Dec. 2 85° 28·4′ N 57 45 E	450 550 800 850 900 1900	246 301 437 465 492 1039	0·73 0·55 0·15 −0·01 −0·04 −0·69	1·02673[3] 2672[3] 2673[1] 2674[1] 2672[4]	35·15 35·14 35·15 35·16 35·14	1·02808 2808 2811 2813 2811	[3] Determinations by Blessing. [4] Determinations by Heidenreich with pycnometer.
	1896.							
25	Jan. 19 84° 58′ N 39 20 E	0	0	−1·82				
	Feb. 14 84° 19′ N 22 52 E	0	0	−1·78				
	Jan. 19 Feb. 14	5 5	2·7 2·7	−1·84 −1·78				

Disting. Number of Temp.-Series	Date and Locality.	Depth in Metres	Depth in Engl. Fath.	Corr. Temp. *in situ.*	$S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$	Salinity.	$S\frac{t}{4^{\circ}\text{ C.}}$	Remarks.
	1896.			° C.				
	Feb. 1 84° 50′ N 29 0 E	175 200 500 550 875 900 975	96 109 273 301 478 492 533	−0·44 0·15 0·83 0·63 −0·01 −0·04 −0·14				
26	April 22 84° 6′ N 12 26 E	0 5	0 2·7	−1·86 −1·86				
	April 15 84° 7′ N 16 0 E	175 185 200	96 101 109	−0·27 −0·19 0·20				
	April 16 84° 5′ N 15 0 E	225 500 600 875	123 273 328 478	0·79 0·93 0·64 0·12				
	April 15	900	492	0·01				
	April 16	925 950 1000	506 520 547	−0·04 −0·06 −0·21				
	April 15	3000	1640	−0·87				

II.

THE BARENTS AND MURMAN SEA.

Our observations of the temperature and salinity of the surface of the Barents and Murman Sea, made on the days July 21st to 29th, 1893, have been introduced on the chart, Plate II. Numerous observations were made simultaneously in the same sea by Lieutenant N. E. Zhdanko and Mr. N. Knipowitch, on board the *Nayezhdnik* of the Russian Navy, and have to a great extent also been introduced on the chart.[1] Thus a fairly complete representation of the horizontal distribution of temperature and salinity on the surface of this sea about the end of July and the beginning of August, 1893, has been obtained. I have tried to draw the probable isotherms and isohalines of the sea-surface, but as there are several considerable gaps, these curves are merely approximate, or in some parts even hypothetical.

The lines marked with Roman Numbers indicate the course of the sections I—VIII given on Plates V and VI.

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[1] See Knipowitch, 'Material concerning the hydrology of the White Sea and the Murman Sea, I', Bulletin de L'Académie Impér. des Sciences, St. Pétersbourg, Série V, vol. VII, No. 3, 1897, pp. 269 *et seq.* (Russian). Knipowitch has determined the specific gravity, $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$, with the hydrometer, but has evidently used somewhat too small a factor for referring the specific gravities to salinity. The salinities introduced in our chart have therefore been obtained by a reduction of his specific gravities with the factor 1315. But on the whole, his determinations of the specific gravities, especially of the deep strata, do not appear to be as trustworthy as his temperatures; and where the salinities obtained seemed quite improbable, I have either left them out or marked them with a query.

The North Cape Current. By considering the chart on Pl. II, we may easily form some general idea of the surface currents in the Murman and Barents Sea. Eastward from the north of Norway, we see the eastern branch of the Gulf Stream, called by Middendorf the *North Cape Current,*[1] making its existence evident by the comparatively high temperatures. The salinities are also considerably higher than those of Polar waters, but we nowhere found salinities approaching those of real Atlantic water. Along our route it never exceeded 34·5 ‰ on the sea-surface,[2] while the Gulf Stream is generally above 35 ‰ west of Spitsbergen during the summer. Along the west coast of Norway (the Finmark or Lofoten coast) we have, however, nearly similar low salinities (34·6 ‰), even as much as 100 miles from the coast or more (200 kilometres). This proves that the North Cape Current running into the Barents and Murman Sea, with a width of nearly 3 degrees of latitude, is mixed, to a very great extent, especially in its southern portion (on its right side), with Norwegian Coast water, and water coming from the North Sea, and even from the Baltic, and to some extent also from the East Icelandic Polar Current.

During its eastward course through the Murman Sea, the salinity of the surface-water of this current is, at least during the summer, still further lowered by the admixture of coast-water, from the Russian coast to the south, and the coast of Novaya Zemlya to the east, as well as of Polar water from the north and east, these much lighter waters with low salinities having a strong tendency to spread over the heavier water (see Sections I to V, Pl. VI).

The origin of the North Cape Current is evidently that as soon as the Norwegian Gulf Stream has passed the northern extremity of Norway, and the coast on its right suddenly trends off to the east, its upper strata are forced by the Earth's rotation eastward across the submarine threshold, or plateau, connecting Norway with Bear Island and Spitsbergen (see Sections

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[1] Middendorf, 'Der Golfstrom ostwärts vom Nordkap', Petermann's Mitteilungen, vol. XVII, 1871, p. 26.

[2] This also agrees well with the general results of Mr. Knipowitch; but in some few places he has observed salinities above 35 ‰, and in one case even 35·6 ‰ ($S\,\frac{17{\cdot}5^\circ\,C.}{17{\cdot}5^\circ\,C.} = 1{\cdot}0271$, l. c., p. 285). These values are, however, in striking disaccordance with the rest, and seem to be due to some mistake. This is also evidently the case with two surface observations from the Yugor Strait on September 2nd, 1893, l. c., p. 287.

VII and VIII, Pl. V).[1] It is the course of this current that we see so often repeated in currents in high northern latitudes moving along a coast situated to their right, *e. g.* the east Greenland Polar Current round Cape Farewell, the Irminger Current round Iceland, the Gulf Stream north of Spitsbergen (see later). They all turn sharply to the right with the coast, or at least give off branches.

After the current has passed the meridian of the North Cape, it is driven as much towards the south-east as the configuration of the land will allow of, and is separated from the Murman Coast by a comparatively narrow belt of coast-water with lower salinity (see the isohaline for 34 ‰).[2]

Eastward from the western Murman Coast, the southern surface-boundary of the North Cape Current makes a curve towards the entrance to the White

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[1] The upper strata of the Gulf Stream, which have comparatively low salinities, being diluted with coast-water from Norway, etc., are thus, as it were, skimmed off eastward, and this explains why, in the summer at any rate, the salinity of the sea-surface is generally higher west of Spitsbergen than in the Murman and Barents Sea.

[2] The distance of the southern edge of the Gulf Stream at the sea-surface from the Murman coast seems, however, to vary much with the winds prevailing. According to *N. P. Andreyeff* ['Results of meteorological and hydrological observations made in the White Sea and along the Murman coast', Morskoi Sbornik (Medicinskiye Pribavlemie) October, 1889, in Russian] it varies with the months of the year. Between April and August the Gulf Stream approaches the western Murman Coast, coming into immediate contact. After August it again recedes northward. He supposes these changes to be due to the winds, and also states that the Gulf Stream along the Murman Coast changes from one year to another. Lieutenant *E. M. Zhdanko* (Izvestiya Geograph. Obshchestva, vol. 32, 1896, p. 181, in Russian) made oceanographic observations in the Murman and Barents Sea during the summers of 1893, 1894 and 1895, and arrives at the conclusion that in July and August, both of cold and warm summers, the southern edge of the Gulf Stream extends almost parallel to the Murman Coast at a distance of 100 miles from the coast, but farther east the situation of the Gulf Stream varies much in the different years. Prince *B. Galitzin* (Bull. Acad. Impér. Sciences St. Pétersbourg, Nov. 1898, in Russian) and Capt. N. V. Morozeff ('Lociya Samoyedskago berega Severnago-Ledovitago okeana.' St. Petersburg, 1896, p. 15, in Russian) are of opinion that the Gulf Stream, after having passed the meridian of the North Cape, runs towards the east-south-east, almost parallel to the Murman Coast, with its southern edge generally at a distance of from 50 to 60 miles from the latter. But Galitzin says that southerly winds may force the current northward to a distance of 100 miles from the coast, while during prevailing northerly winds, the current comes close to the coast, and may then be met with near the entrance to the Yekaterine Harbour.

The correct explanation is, in my opinion, that during prevailing southerly winds, the coast-water along the Murman Coast is spread farther northward over the Gulf Stream, and while this coast-water will thus have a more northerly extension on the sea-surface, it will probably form a much thinner surface-stratum near the coast, and the Gulf Stream water, with high salinities, will there, during such periods, come much nearer the sea-surface than at other times. During prevailing northerly winds, the coast-water is prevented from spreading northward, and will form a much narrower, but also much thicker surface-stratum near the coast.

Sea and passes in the direction of the Kanin Nos and more or less to the north of Kolguyev Island. In July, 1893, it seemed to approach very near to the former, the isohaline of 34 ‰ passing not very far from the cape, while it kept farther off from the island.[1]

The course of the southern boundary-line of this current is evidently much influenced by the configuration of the bottom, and we might in fact assume that the current here is to some extent divided into two branches by the shallow ridge or plateau extending towards the north-west, with a depth of 157 m. in 70° 36′ N. Lat., 35° 37′ E. Long., from the shallow sea north of Kanin Nos (see Pl. III). The various Russian investigators do not seem to have paid sufficient attention to this circumstance, and this explains perhaps to some extent why they are of such different opinions with regard to the course of the southern boundary-line of the Gulf Stream in this sea. One branch follows the deep depression or submerged valley along the Murman Coast towards Kanin Nos, and the entrance to the White Sea, into which it may occasionally penetrate, especially during the winter.[2] This submerged valley, which we might call the *Murman Channel*,[3] is filled to a great extent with the water of this current, and has temperatures above 0° C. along the bottom (see later). The other branch, the main current, passes eastward to the north of or along the north side of the shallow plateau. Over this plateau itself, the eastward current will naturally have less force, and thus the coast-water has here a chance of spreading towards the north and north-

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[1] Lieutenant Zhdanko (l. c.) says that the southern boundary of the Gulf Stream, in warm summers, passes about 60 miles (in 69° 40′ N. Lat.) to the north of the Kanin Nos, towards the north coast of Kolguyev Island, and farther east to about 52° E. Long. (in about 70° N. Lat.), where it turns sharply northward to the Southern Goose Cape. In cold summers, and especially during strong winds from the north-east, the Gulf Stream is forced towards the north, and its southern boundary is situated 100 miles north of the Kanin Nos, from the meridian of which it no longer passes in an easterly direction, but trends gradually towards the Northern Goose Cape.

[2] Middendorf had already assumed the existence of a warm current such as this flowing into the White Sea, but his assumption was based merely on observations of the surface-temperature which were evidently made in the warm coast-water, and not in Gulf Stream water.

[3] I consider this submerged valley simply to be the continuation of the submerged White Sea valley, which has had its drainage along this channel. The originally deep entrance to the White Sea, which is a continuation of the channel, has now, however, been made quite shallow, probably by moraine material and by deposits. It is a similar feature to that found in most Norwegian fjords, in the Norwegian Channel, etc.

west, between the two branches of the North Cape Current.[1] This may perhaps be the explanation of the low salinity, 34·1 ‰, observed by us at Station 1, and it is evident that the coast-water extended very far to the north in July, 1893; during the northward voyage of the Nayezdhnik, salinities as low as 33 ‰ were observed on July 27th, 1893, as far north as 70° 38′ N. Lat., 48° 20′ E. Long. and 70° 40′ N. Lat., 51° 6′ E. Long. The colour of the sea was green from Kanin Nos northward to this latitude, where it suddenly became deep blue,[2] and the salinity increased. During the southward voyage of the Nayezhdnik in August, 1893, the blue sea-water with the high salinities (34·5 ‰ and 34 ‰) extended much farther south, down to 15 miles north of Kolguyev (in 69° 45′ N. Lat., 48° 23′ E. Long. on August 16th, 1893), where the sea again suddenly became green, and where the salinity etc. of the sea-surface sank rapidly towards the south to 33·4 ‰, 32·6 ‰, 31·6 ‰, etc.[3]

The whole of Pechora Bay east of Kolguyev, between Novaya Zemlya, Vaigach, and the Russian coast, when we passed through it at the end of July, 1893, was covered with light coast-water on the surface — salinity below, and sometimes much below, 32 ‰ —, and was filled with very cold bottom-

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[1] A sounding was taken in this shallow sea on May 25th, 1900, by Mr. Alf Wollebæk, on board the Heimdal of the Norwegian Navy, with the following results:

May 25 1900.	69° N. Lat. 41° E. Long.	Depth in m.	0 m.	10 m.	20 m.	40 m.	65 m.
		Temp. ° C.	—1·65	—1·65	—1·65	—1·65	—1·65
		Salin. ‰	34·17	34·17		34·17	34·21

[2] See Köppen, 'Hydrographischen Arbeiten der Kais. Russ. Marine etc. 1893 und 1894'. Ann. der Hydrographie und Marit. Meteor., January, 1896, p. 26.

[3] In the summer of 1894, the eastern coast-water seems, according to Lieutenant Zhdanko's observations (Morskoi Sbornik, vol. 267, No. 5, 1895, p. 152, in Russian) to have had an unusually wide extension towards the north, between the two branches of the North Cape Current; and the northern branch seems to have been driven far north, or rather covered with coast-water on the sea-surface. According to Prince Galitzin's (l. c.) extract of Zhdanko's paper, which I have had no opportunity of seeing, Lieutenant Zhdanko, on his voyage from Yekaterine Harbour to Novaya Zemlya, met with surface-water of a high salinity almost outside the entrance to the harbour (in 69° 26′ N. Lat., 33° 55′ E. Long.). Towards the north-east the surface-salinity increased to a maximum of 34·4 ‰, (probably = 34·5 ‰, see above p. 257, footnote) which was still observed in 71° N. Lat. and 43° 14′ E. Long.; but in 71° 16′ N. Lat. and 45° 15′ E. Long. it had sunk to 32·7 ‰, and continued to decrease towards Novaya Zemlya. Only off the Northern Goose Cape (72° 11′ N. Lat., 51° 30′ E. Long.) was surface-water with a higher salinity (33·8 ‰) met with; but from this place to the Maliye-Karmakuli, the salinity remained very low.

water underneath this layer (see our Stations 5 and 6). The North Cape Current was thus prevented from entering the shallow Pechora Bay. By the configuration of the sea-bottom and the coasts, and owing to the fact that the current is kept off by the light surface-layers and the cold bottom-water, it is now conducted towards the north and east along the coast of Novaya Zemlya, from which it is separated, as will be mentioned later, by a belt of eastern water.

It is, however, probable that by changing winds, etc. the conditions may be altered very rapidly in the shallow Pechora Bay, and some small portion of Gulf Stream water may enter the bay. A continuance, for instance, of southerly or south-easterly winds will naturally carry the surface-water towards the north-west, and there will easily be an indraught of warmer water along the bottom from that direction. Prince Galitzin[1] may therefore be perfectly right when he maintains that at the place to the north-east of Kolguyev, where the southern boundary of the Gulf Stream turns towards Goose Land, a small branch is given off to Pechora Bay, and gradually disappears, as it is mixed with the coast-water. As an example of the rapidity with which the conditions may alter, we may mention the difference between our observations at Station 5 on July 27th, 1893, and Knipowitch's observations about three weeks later (August 21st, 1893), 16 miles to the south-east of our station (in 69° 26′ N. Lat., 54° 43′ E. Long.)

Depth.	0 m.	5 m.	7 m.	10 m.	13·5 m.	15 m.	20 m.	26 m.	30 m.
Fram.	8·40° C. 23·4 °/₀₀	4·16° C. 28·4 °/₀₀		2·11° C. 30·4 °/₀₀	−0·73° C.	−1·51° C. 34·1 °/₀₀	−1·57° C. 34·4 °/₀₀		−1·65° C. 34·7 °/₀₀
Knipowitch.	5·8° C. 31·4 °/₀₀		5·5° C.			2·7° C.		0·3° C. 33·0°/₀₀?	

When we passed, the sea-surface was evidently covered with the warm, but much diluted water from the coast (chiefly the Pechora River?), while there was an under-layer, below 13 m., of cold and heavy bottom-water, probably coming through the Kara Strait. When Knipowitch came to the same region, the light and warm surface-layer may to some extent have been

[1] Bull. d. l'Acad. Impér. des Sciences de St. Pétersbourg, Nov. 1898. (Russian).

spread by winds towards the north or north-west, but at the same time the cold under-current from the Kara Sea has to some extent been displaced by warmer water sucked in from the north-west.[1] At Station 6 we found the sea covered with floe-ice, and ice-water (3·5 ‰) on the surface, while Knipowitch, on August 21st, 1893, very nearly on the same spot, found temperatures between 7·5° C. and 7·9° C., and salinities between 25·5 ‰ and 31·0 ‰. During her eastward voyage, in August, 1893, the Nayezhdnik sailed in green water from Kolguyev (69° 45′ N. Lat., 48° 23′ E. Long.) to Yugor Strait. On the westward voyage from Yugor Strait, 18 days later, she again suddenly met with deep blue water, even in 70° 8′ N. Lat., 52° 10′ E. Long., and the salinity simultaneously rose from 30·4 ‰ to 33·6 ‰.[2]

Middendorf long ago drew attention to the fact that glass floats from the nets of the Norwegian fishermen at Lofoten have been found at the mouth of the Pechora River.[3]

The diagrammatic curves, Pl. VI, and the sections, Pl. V, representing the vertical distribution of temperature and salinity, give a fuller impression of the nature of the North Cape branch of the Gulf Stream. We see that the greater part of the Barents and Murman Sea below the uppermost strata, is filled with water of a very uniform salinity, about 35 ‰ and 34·9 ‰, apparently decreasing slightly and gradually eastwards along the Fram's route, while the temperature, especially of the lower strata, sinks considerably more rapidly in the same direction, and the uppermost stratum of water, with salinities below 34·75 ‰, increases in thickness eastward. It is evident that we here have at least three kinds of water with different origin, *viz. Gulf Stream water* coming from the west, *light surface-water* coming from the coasts, and *cold, heavy bottom-water* coming from the east.

These relative conditions are especially clearly demonstrated by Section I, Pl. V, which is a section along the Fram's route from Vardø to Goose Land. As in the western portion of this section we had only made observations of the surface-temperatures, I have there introduced (in brackets) the

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[1] Knipowitch's salinity at the bottom is much lower than ours at similar depths. It seems, however, as if, upon the whole, his salinities from deeper strata are not quite trustworthy; his water-bottle may posibly not have worked quite perfectly.

[2] Köppen. l. c., p. 26.

[3] L. c., p. 30. Mr. Ssidoroff also found Norwegian glass floats at the mouth of the Pechora in 1869: see Petermann's Mitteilungen, 1870, p. 453.

deep-sea observations of the 'Norwegian North Atlantic Expedition', made on June 27th, 1878, at stations 262, 263, and 264.[1] Having been made in a different year and at an earlier season, these observations have only been introduced as an aid in drawing the isotherms and isohalines of the deeper strata in this part of the section.

We see that there is hardly any light surface-water with salinity below 34·75 in the western portion of the section, but the light water increases rapidly in thickness eastward. The water with salinities of about 35 ‰, coming very near to the surface west of Station 1, gradually sinks eastward. At Station 1, 35 ‰ was observed at 20 m., while at Station 2 it was only 34·6 ‰ at 20 m., and 34·96 ‰ at 80 m. Station 3 forms a strange exception in this, as well as in other respects. The isohalines here again rise to some small extent towards the surface; at 40 m. we found 34·9 ‰ and at 80 m. 35·0 ‰. Towards the coast of Novaya Zemlya the isohalines again sink rapidly, evidently owing to the admixture of land-water.

In the temperature there were to some extent similar, but still greater, variations. The surface-temperature sank, eastward from 8·0° C. near the Norwegian coast, to a minimum of 3·69° C. at Station 3, and thence it again rose eastward to 6·92° C. at Station 4, near the coast of Goose Land. The temperature of the deeper strata was also highest in the western portion of the section, but even there they decreased rapidly from the surface downward. At our Station 1 (see Pl. IV), the zero Centigrade was probably at 125 m., and at 200 m. we found —1·14° C. In the sea west of this station, no temperatures below 0° C. were observed at any depth in June, 1878, the lowest temperature at the bottom being 1·9° C. (cf. Sts. 262, 263). But the isotherms, especially of the lower temperatures (below 2° C.), ascend comparatively abruptly eastward to Station 3, where they come very near the surface, the isotherm of —1° C. being at about 36 m. Farther east towards the coast of Novaya Zemlya, they again descend. It is upon the whole a noteworthy feature in the oceanography of the Barents and Murman Sea, how rapidly the temperature of the

[1] H. Mohn, 'The North Ocean, its Depths, Temperature and Circulation.' The Norwegian North Atlantic Expedition 1876—1878, Christiania, 1887, p. 54. Our surface-temperatures are higher than Mohn's, a fact which is evidently due to the circumstance that his observations were taken nearly a month earlier in the season than ours. But the season has naturally less influence upon the temperatures in the deeper strata, and his deep-sea observations have therefore more value as compared with ours.

deeper strata sinks eastward, while the salinity changes slightly. As an example the following table may here be given of the temperature and salinity at some depths along Section I:

	40 m.		60 m.		80 m.		Bottom.	
	° C.	‰	° C.	‰	° C.	‰	° C.	‰
Station 1	3·58	35·0	1·58	35·0	1·01	35·0	[—1·14]	[35·1]
— 2	1·34	34·9	0·54	34·8	—0·44	34·96	—0·54	34·9
— 3	—1·32	34·9	—1·64		—1·72	35·0	[—1·63]	35·0
— 4	—0·50	34·8	—1·01	34·9			—1·11	35·1

We see that at Station 3 there is a marked minimum in the temperature of the deeper strata too, while there are no prominent changes in the salinity. In our most easterly stations, Nos. 5 and 6, the cold bottom-water had approached very near the surface (see Section V, Pl. V). The isotherm of 0° C. being at about 13 m. at Station 5, and at 2 or 3 m. at Station 6. The salinities had, however, considerably decreased at these stations.

Considering the great differences in the temperature of the water with salinities about 35·0 ‰ and 34·9 ‰, it is evident that this water must have two sources. The water with high temperature which is much above the mean temperature of the atmosphere in this latitude, must, to a great extent at any rate, have its origin in the Gulf Stream. This kind of water predominates in the western portion of Section I. The water with low temperature — below zero Centigrade —, predominating in the eastern portion of Section I, must have some eastern or north-eastern origin, and cannot possibly come directly from the Gulf Stream. It evidently forms an under-current creeping eastward along the bottom, and cooling down the lower strata of the overlying North Cape Current. This cold bottom-water will be specially mentioned later.

Section VII, Pl. V, is carried from the Kanin Peninsula through Knipowitch's station on July 26th, 1893, (68° 56½′ N. Lat., 45° 6′ E. Long.), and towards the north-west through our Station 1, and Stations 267 to 279, etc. of the Norwegian North Atlantic Expedition (1878),[1] to Bear Island, and

[1] Mohn, l. c., pp. 54, 55, 57, 58. H. Tornøe, The Norwegian North Atlantic Expedition, Chemistry, p. 63.

thence to South Cape in Spitsbergen. The observations at the Stations 267 to 279 were made between June 29th and July 3rd, 1878, and the observations at the Stations 319 to 337 between July 23rd and August 5th, 1878. As there were comparatively few observations of the salinity, the isohalines of this section are to a very great extent hypothetical; the same is also the case with the isotherms, especially south of Station 1, and between Station 275 and Bear Island.

The section gives a fair idea of the northward distribution of the North Cape Current. It is seen that between Station 269 and Bear Island, there are no temperatures below zero Centigrade between the surface and the bottom; and along a section from Hammerfest in Norway to Bear Island, the Norwegian North Atlantic Expedition found the bottom-temperature in the summer of 1878 everywhere above 1° C. (see Mohn, l. c., Pl. XIII, Section XXVI, and Pl. XXV). This Section was evidently filled with water which was to a very great extent of Gulf Stream origin.

Our Section VII, Pl. V, demonstrates clearly, however, how rapidly the temperature of all strata sinks eastward. We see that as soon as the line of the section in the chart, Pl. II, trends a little eastward of its main direction the isotherms rise towards the surface, and simultaneously the depth decreases (see Stations 269 and 270, 272, 274 and 275).

If we consider only Stations 1, 267, 271, 273 and 276, which are situated nearly in a straight line, the isotherms of the section would have a very regular course, as indicated by the dotted lines.

Section VIII, Pl. V, represents an excellent Section made by Dr. Johan Hjort from Finmarken to Bear Island in the first few days of September, 1900. The determinations of the temperatures and salinities of this section are made with a higher degree of accuracy than in previous sections, and demonstrate clearly the vertical distribution of temperature and salinity in the North Cape Current, at the entrance to the Barents Sea at that time. In the summer of 1900, the Gulf Stream was evidently less developed than usual, and the temperatures, especially in the northern part of the section were therefore on the whole somewhat lower than, for instance, found by the Norwegian North Atlantic Expedition in the same parts of the sea in July, 1878. We see distinctly how the most saline water (above 35·0 ‰ and 35·1 ‰, etc.) is situated exactly in the centre of the current.

Near the Norwegian coast, the water is evidently diluted by the admixture of coast-water, which has also increased the temperature (cfr. the course of the isotherms). Near Bear Island the ocean-water is diluted by the admixture of polar water (coming from the Barents Sea), which has lowered the salinity and the temperature. The salinity of the bottom-water is evidently also slightly decreased by the admixture of colder and less saline water such as this. The water near the surface is diluted chiefly by the admixture of coast-water from the south, and to some small extent by polar surface-water from the north.

Cold current along the south-west coast of Novaya Zemlya.

Lütke[1] has already stated that a cold current passed through the Kara Strait west and north-west along the south-west coast of Novaya Zemlya. Middendorf[2] maintained that the Gulf Stream is kept off from the coast of Novaya Zemlya by a current of cold water following the deeper "Thalfurche" (submarine channel) at the bottom along this coast, and receiving additions from the currents through the Kara Strait and the Matochkin Shar.[3] Prof.

[1] Lütke, 'Viermalige Reise, 1828, vol. II, pp. 72, 78. (Russian).

[2] Middendorf, 'Die Golfstrom ostwärts vom Nordkap', Petermann's Mitteilungen, vol. XVII, 1871, p. 31.

[3] *Petermann* also points out ('Die Erschliessung eines Theiles des nördlichen Eismeeres etc.', Petermann's Mitteilungen, vol. XVII, 1871, p. 104 and Pl. 6) that the observations of the Norwegian sealing captains in the summer of 1870, prove the existence of this current of cold water coming from the Kara Sea, and passing in a north-westerly direction between the warm water of the Gulf Stream and the coast of Novaya Zemlya as far as Goose Land, north of which, however, the warm water predominates.

Klykoff ('Zapiski po hidrografii', 1890, Part I, p. 4, in Russian) says that a continuous cold current was observed running northward along the west coast of Novaya Zemlya from Karmakuly to Matochkin Shar, with a velocity of half a knot. The correctness of this assertion is, however, positively denied by Lieutenant *Zhdanko* (Morskoi Sbornik, vol. 267, No. 5, 1895, in Russian), who, from his own observations in 1894, arrives at the conclusion that a cold current undoubtedly exists along the west coast of Novaya Zemlya, but contrary to the assumptions of others, this cold current runs from the north towards the south, which he thinks is proved by observations of the fact that during wind from ESE he met with ice-floes drifting in a southerly direction. On the other hand, however, Zhdanko himself states (see Izvěst. Geograf. Obshchestva, vol. 32, 1896) that in the sea between Kolguyev and the Vaigach there is a sharply-defined cold area with surface-temperatures about and below Zero Centigrade, which he thinks is evidently due to the proximity of the cold Kara Sea. He also thinks that from the Northern Goose Cape northward, the Gulf Stream comes quite close to the west coast of Novaya Zemlya. It seems as if these statements were somewhat contradictory to the assertion that a cold current flows from the North.

Prince *Galitzin* thinks (l. c.) that there is good reason to assume that a cold current runs northward from the Kara Strait along the west coast of Novaya Zemlya

O. Pettersson did not, however, find any indication of such a current in the observations made on the Vega Expedition on July 29th and 30th, 1878, and he even says that they "seem to bear out quite an opposite result", as the temperature of the sea-surface rose towards the coast of Novaya Zemlya.[1] In my opinion, indications of a cold current such as this can, however, be traced with certainty in the Vega observations as well as in ours. I have above pointed out that at our Station 3 there is a distinctly marked minimum of temperature both on the surface and in the deeper strata. Middendorf expected his cold coast-current to be about 60 nautical miles broad, and Station 3 is situated 65 miles from the coast of Goose Land. From this station our surface temperatures again rose towards land to a second maximum of 6·92° C. at Station 4, while the deeper strata remained cold, although not so cold as at Station 3. During our southward course from land, the surface-temperatures again sank rapidly to 4·9° C. 28 miles farther south, and 3·9° C. in 69° 54′ N. Lat., and 52° 23′ E. Long., when we were once more about 90 miles from the coast.

The salinity of the sea-surface first rose eastward during the first part of our route from 34·1 ‰, at Station 1, to 34·5 ‰ at Station 2. At Station 3 it still remained the same, while it sank rapidly towards the coast of Novaya Zemlya, to 31·2 ‰ at Station 4.

In Knipowitch's observations we find a similar rise of the temperature, and fall of the salinity of the sea-surface towards land near the Novaya Zemlya coast. About 20 miles seaward (in 71° 35′ N. Lat., 50° 33′ E. Long.) from our Station 4 (with 6·92° C. and 31·2 ‰), Knipowitch observed at the sea-surface two days after us, on July 27th, 1893, a temperature of 5·4° C. and a salinity of 33·9 ‰. Outside Maliya Karmakuli (in about 72° 22′ N. Lat.) he found, on July 28th, 1893, a surface-temperature of 5·8° C. and a salinity of 32·6 ‰, but 14 miles farther from land (72° 24′ N. Lat., 51° 47′ E. Long.) he observed on the same day 4·9° C. and 34·6 ‰.

to Goose Land, forcing the Gulf Stream towards the west off this coast; but on the other hand, he considers it to be certain that in some years the Gulf Stream makes its way far into Moller Bay, north of Goose Land.

[1] O. Pettersson, 'Contributions to the Hydrography of the Siberian Sea', Vega Exp. Vetensk. Iakttagelser, vol. II, pp. 345, 347. These higher temperatures were, however, evidently observed in the coast-water near land, situated inside the cold current, and partly also covering it (see later). The existence of this warmer coast-water was not pointed out by Middendorf and Petermann, although Middendorf's remarks prove that higher temperatures were observed near the coast.

In the surface-temperatures observed by Nordenskiöld on July 28th, 1878, we find changes almost exactly similar to the above, although not so great. Here there is a minimum of 4·7° C. and 4·8° C. about 90 miles west of Goose Land. From this minimum the temperature rises eastward to 5·4° C. near land. Near the minimum of temperature there is, however, also a minimum of salinity of 33·3 ‰, eastward from which the salinity again rises to 33·5 ‰, but sinks to 32·8 ‰ near land. It is also very interesting to note that just at the temperature minimum, the surface-water of the sea is denoted as green,[1] while it is blue both west and east of it. During the Vega's southward course along the coast, there was no sinking in the temperature similar to ours, as she kept nearer to the land, in the coast-water.

In Prince Galitzin's series of surface-temperatures and salinities of the Murman Sea in July and August, 1896,[2] we also find very similar changes of the temperature in this part of the sea, but the salinities are upon the whole very low.

The observations made during the six voyages of the Dutch expeditions on board the 'Willem Barents', 1878 to 1883, give much valuable information in this respect. In the observations of the temperature of the sea-surface during every voyage that has been made through this part of the sea, we find a similar minimum in the neighbourhood of our Station 3, when the distribution of the surface-temperature was not disturbed by the presence of drifting ice, as in the years 1881 and 1882.

The voyage of 1879 took its course, from July 29th to August 3rd, northward outside Goose Land, nearly along the meridian of 50° E., and here we find a distinct minimum in the surface-temperature of 4·5° C. on July 29th (about 71° N. Lat., 50° 15′ E. Long.), 42 miles south-east of Goose Land, with temperatures up to 5·3° C. both south and north of it.[3]

The voyage of 1880[4] in July took an eastward course from Vardø very nearly along the same route as the Fram; but towards Novaya Zemlya, it

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[1] See the chart, Pl. 24, in Pettersson, l. c.
[2] L. c., Pl. I, II.
[3] See the chart in 'De Verslagen omtrent den Tocht met de Willem Barents, etc. 1879.' Bijbladen van der Tijdschrift van het Aardrijkskundig Genootschap, No. 6. Amsterdam, 1880.
[4] See chart in 'Verslagen omtrent den derden Tocht van de Willem Barents, 1880', Haarlem, 1881.

turned a little more north. Off Goose Land (71° 50′ N. Lat.), about 60 miles from the coast, we find a minimum in the surface-temperature of 2·9° C., on July 15th, while westward the temperature rose to 5·5° C. and 6·7° C., or very much the same temperatures as were observed along our route in 1893.

The surface-observations of the first voyage of the Willem Barents, in 1878, are specially interesting. The ship passed twice through the sea to the north of the Fram's route, and both times a distinct minimum may be traced in the surface-temperatures, but at a considerably greater distance from land than our Station 3. On July 27th, a minimum of 4·2° C. was found in 73° 10′ N. Lat. (45° E. Long.) about 130 miles from the land, the temperature rising (to 5·4° C. and 5° C.) both west and north of this place. On August 16th, a minimum of 4·5° C. was found in 72° 50′ N. Lat. about 100 miles from the land (about 46° 50′ E. Long.) the surface-temperature rising to 5° both east and west of it.[1]

It seems as if the distances of the temperature-minima from land increase with increasing latitude, for we have found,

	Expedition,	Date.	Minimum.	Distance from Land.
In latitude 71° N.	W. Barents	July 29, 1879	4·5° C.	42 miles
— 71 17′	Fram	July 24, 1893	3·7 -	65 „
— 71 36	Vega	July 28, 1878	4·7 -	100 „
— 71 50	W. Barents	July 15, 1880	2·9 -	60 „
— 72 50	W. Barents	Aug. 15, 1878	4·5 -	100 „
— 73 10	W. Barents	July 27, 1878	4·2 -	130 „

Some soundings of the Willem Barents Expeditions are also of much interest in this respect. In several series of deep-sea temperatures there are, however, evidently mistakes which might lead to very erroneous conclusions. The origin of these mistakes may be the Ekman Insulated Water-bottle of the first model (with collar), which was used for some observations. This instrument may sometimes have been closed in wrong depths, or may not have been perfectly water-tight. For example, on July 26th, 1881,[2] in 70°

[1] See chart in 'De Verslagen omtrent den Tocht met de Willem Barents, 1878', etc., Bijblad No. 5, Amsterdam, 1879.

[2] 'Verslagen omtrent den vierden Tocht', etc. Haarlem, 1882. p. 104.

49′ N. Lat., 50° 47′ E. Long., about 40 miles from land, at a spot where there was drifting ice, the following observations were made:

at 0 m. —0·8° C. and a specific gravity of the water of 1·0197
at 113 m. (bottom) —1·4° C., and 1·0264.

Three days later, and only 28 miles farther from land (70° 30′ N. Lat. 49° 41′ E. Long.), at a place where no ice was to be seen, there was observed,

at 0 m. 5·7° C., and a specific gravity of the water of 1·0252
at 99 m. (bottom) 3·8° C., „ „ „ 1·0256.

It is, in my opinion, evident that the last observation of temperature is erroneous; 3·8° C. is certainly not found anywhere at a depth of 100 m. in the eastern part of the Murman Sea. The observation has probably been made with Ekman's water-bottle, which has been closed at some depth near the surface of the sea. This also appears probable from the simultaneous observations of the specific gravity, which much resembles that of the surface.[1] By a critical examination of the various series of deep-sea temperatures and specific gravities from the Willem Barents Expeditions, similar evident errors may be found. I may specially mention the following series from 1883:[2] July 19th (bottom-observation), August 10th (bottom-observation), August 14th, etc.

The numerous facts mentioned above, together with our observations at Station 3, seem to lead to the certain conclusion that there is, as a rule at least, during the summer, a cold current running along the south-west coast of Novaya Zemlya at a certain distance from land. But this current does not always reach the surface of the sea, as appears from our observations that the salinity of the sea-surface was no lower at Station 3 than farther west; for this would decidedly have been the case, if we had there met with a cold surface-current from the Kara Sea or from the Polar Sea. I think the cold current, which I propose to call the *Lütke Current*, is more of an under-current caused by the configuration of the sea-bottom.

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[1] It seems, however, as if the determinations of the specific gravity of the sea-water made during the Willem Barents Expeditions are not, upon the whole, very trustworthy. This may partly at least be due to the imperfect action of the water-bottle used.

[2] 'Verslag van den zesden Tocht,' etc. Haarlem, 1884, p. 68.

The chart, Pl. III, demonstrates that our Station 3, with a depth of 130 m., is situated just at the entrance to the narrow submarine channel or fjord (submerged valley) passing from the depression to the north (with depths greater than 200 m.) south-west along the coast of Novaya Zemlya through the Kara Strait, and communicating with the deep depression of the Kara Sea.[1]

The depth of this submerged valley in some places is nearly 200 m., and in the Kara Strait probably about 140 m. At its western extremity, off the Southern Goose Cape, this valley is crossed by a shallower moraine-like ridge, passing along the meridian of 49° 30′ E. and being about 123 m. deep at its deepest part (in 71° 10′ N. Lat. and about 45 miles from land).

As mentioned above, there has been some doubt whether the cold current along the Novaya Zemlya coast has a northerly or southerly direction, and this question can hardly be decided satisfactorily until more thorough investigations have been made at various seasons of the year. I consider it probable that cold, heavy water from the Kara Sea passes as a bottom-current through the deep channel of the Kara Strait, and along this submerged valley towards the west and north-west into the Barents Sea; and it was this Kara Sea water that was observed by us in the strata below 30 m. at Station 3. According to the observations made during the Vega Expedition in August, 1878, the temperature and salinity at 120 m. in the Kara Sea would be about —2° C. and 34·9 ‰,[2] consequently very nearly the same as those found at our Station 3.

I do not think that under ordinary circumstances — *e. g.* in July, 1893 — this under-current actually reaches the surface as a current, but the thin surface-layer of Gulf Stream water — *e. g.* at our Station 3 — resting on this cold under-current may be cooled down from below, and is also to some

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[1] The existence of this submarine valley ("einer tiefen Thalfurche") along the coast of Novaya Zemlya had already been drawn attention to by Middendorf (l. c., p. 31), who compared it with the Norwegian Channel along the south and south-west coast of Norway. He supposes both channels to have the same geological origin, without suggesting what this might be. I think it has the typical character of a submerged valley, or river channel.

Petermann's chart of the depths in this part of the sea (Petermann's Mitteilungen, vol. XVII, 1871, Pl. 5), is based on too few soundings, and does not give a correct representation of the channel (cf. my map, Pl. II).

[2] O. Pettersson, l. c., p. 353.

extent mixed with water from the lower strata.[1] Thus minima of temperature are produced, which, as proved above, are traceable in the surface-observations of most expeditions at a certain distance from the coast of Novaya Zemlya. By these minima at the sea-surface, we might trace the course of the under-current, as indicated by the table on p. 270. It seems to follow the submerged valley to our Station 3, where the current flows into the deep depression of the Barents Sea, taking a northerly course, and increasing the distance from land (cf. the temperature minima of the Vega, and the Willem Barents, 1878).

The following very interesting sounding was made by Mr. Alf Wollebæk on board the Heimdal of the Norwegian Navy, to the north of our Station 3, on the 31st May, 1900. Depth = 128 m.

May 31, 1900		Depth in m.	0	10	20	30	50	70	100	120
	71° 48′ N. Lat.	Temp. ° C.	—1·22	—1·30	—1·50	—1·52	—1·52	—1·65	—1·65	—1·80
	49 38 E. Long.	Salin. $^0/_{00}$	34·94	34·95	34·99	34·99	34·99	34·99	34·99	35·28[2]

We see that the temperature and salinities are very similar to those found by us at Station 3 in the deeper strata, below 60 m., but at Wollebæk's station in May, this cold, heavy water reaches the surface. It may be that the higher temperatures and lower salinities observed by us in the upper strata at Station 3 are due to the admixture of coast-water or land-water during the months of June and July.

There is, however, also a possibility that cold, heavy water may come into the submerged channel from the north, although I do not consider this very probable under ordinary circumstances. That there actually is a cold bottom current running westward through the Kara Strait from the Kara Sea, seems to me to be made probable also by the serial temperatures of the Willem Barents Expedition, taken in 1883 (and 1881)[3] along the Novaya Zemlya

[1] The green colour of the sea-surface over this current observed from the Vega, 1878, together with the low salinity, seem to indicate that coast-water had at that time been carried northward on the back of this cold current, from the south-east.

[2] This high salinity may seem somewhat startling, but two samples were taken from this depth, the one giving by titration 35·20 $^0/_{00}$, and the larger sample giving by determination with the hydrometer of total immersion a salinity of 35·28 $^0/_{00}$. Thus mistake does not seem probable. Our determinations, especially at Stations 1 and 4 (cf. also Stats. 3 and 3 a), also indicate a much higher salinity near the bottom of this sea. It thus seems as if a saline and very cold water-stratum is situated near the bottom of this part of the sea.

[3] See l. c., 1881, p. 104, 1883, pp. 68—70.

Channel and in the Kara Strait. By excluding those observations which seem improbable (*e. g.* on June 6, 1883, bottom-observations on July 19 and 20, 1883, etc.; see above, p. 270), I have tried to construct a probable section (see Pl. V, Section VI) along the channel from the Kara Sea, where I have used the Swedish observations, through the Dutch Stations to our Station 3.

Our Stations 5 and 6 were situated in shallow water to the south of the submerged valley, at the end of two branches which it sends off southward (see Pl. III). We evidently found the cold water of the Lütke Current at these places too, at Station 5 below 12 m.[1] and at Station 6 probably at all depths. We see that the cold water comes here much nearer to the surface than at Station 3. We are here evidently nearer to the origin of the current, the Kara Strait; and it is also this current that has carried the ice which we met with in the sea near Station 6. During the sounding at Station 6, the current was also directly observed to run westward, at any rate at the surface, carrying the ice in that direction. The temperature and salinity observed at these stations seem to be very similar to those observed in the Kara Sea, as may be seen from the following examples:

		Murman Sea.			Kara Sea.			
Depth in Metres.		Station 3 July 24, 1893	Station 5 July 27, 1893	Station 6 July 28, 1893	Vega Aug. 1, 1878 70° 23′ N. Lat. 61° 42′ E. Long.	Kjellman [2] Aug. 3, 1875 70° 22′ N. Lat. 61° 10′ E. Long.	Kjellman [2] Aug. 4, 1875 70° 56′ N. Lat. 63° E. Long.	Vega Aug. 2, 1878 71° 23′ N. Lat. 64° 32′ E. Long.
0	Temp. ° C.	3·69	8·40	1·74	5·2	3·9	4·2	3·6
	Salin. °/₀₀	34·46	23·36	3·47	29·0		29·8	31·0
10	Temp. ° C.	*3·3	2·11	−1·56	0·4	*2·1	*2·2	2·1
	Salin. °/₀₀	*34·5	30·36	33·99	29·6		*30·7?	31·3
20	Temp. ° C.	2·91	−1·57	−1·67		*0·5	*0·2	*0·5
	Salin. °/₀₀	34·52	34·44	34·36			*(31·6?)	*32·2
50	Temp. ° C.	*−1·5	−1·55		−1·5	−1·5	*−1·3	−2·4
	Salin. °/₀₀	*34·9	34·70		34·6		*(32·8?)	34·5 [3]
120	Temp. ° C.	−1·6				*−1·9	−1·7	−2·0
	Salin. °/₀₀	35·05					(33·2?)	34·9

[1] The surface of the sea was covered at Station 5 with a layer (12 m. thick) of warmer coast-water, which had a lower salinity than the water at the same depth at Station 6, where, however, the surface-water consisted of melted ice.

[2] Bih. K. Svenska Vet.-Akad. Handl., vol. 4. No. 1.

[3] The record in the table (l. c., p. 353) is 34·0 °/₀₀ for this depth, but there seems to be some mistake, as the salinity is between 34·4 °/₀₀ and 34·6 °/₀₀ at the same depth at the other stations in the Kara Sea.

The numbers marked with an *asterisk* are obtained by interpolation between the observations made at the nearest depths above and below, as there were no observations for the depth desired. The observations made of the salinities of the water of the deeper strata at Kjellman's stations in 1875, do not seem trustworthy, being evidently much too low. The water-bottle has probably not been water-tight. I think there is a possibility that the salinities observed at deeper strata during the Vega Expedition are also somewhat too low, as the Ekman insulated water-bottle of the first model with collar was used, and this may not have closed perfectly tight (cf. our experiences, p. 141).

The above table demonstrates clearly how the cold and more saline bottom-water comes much nearer to the surface of the sea at our station 5, and still more at station 6, than at our station 3 and in the Kara Sea. It seems probable that either the surface-currents at these shallow stations have caused an indraught of bottom-water from the submerged valley to the north, along the side valleys, and this bottom-water is here forced towards the surface by the slope of the rising sea-bed — or that we found here the cold bottom-water formed during the winter, which had not yet been replaced by the warmer water. Very much the same conditions may also be seen in the observations of the Willem Barents Expedition on August 3rd, 1883, on the southern side of the Kara Strait.

I have already pointed out on p. 262, how rapidly the conditions may alter in the shallow sea, and I expect therefore that there may be great variations and probably periods in the Lütke Current. This may, for instance, be dependent upon the changes in the density of the strata near the surface of the Kara and the Murman Seas, produced by the admixture of the water from the Russian and Siberian rivers in the spring and summer.

We also see that in July and August of some years, the current through the Kara Strait carries ice into the Murman Sea, *e. g.* in 1881, 1883[1], and 1893, while in other years, such as 1870, 1878, 1879, no ice was to be seen at this season.

Weyprecht believes that the observations of the deep-sea temperatures made on board the Tegetthoff prove the existence of seasonal changes in the undercurrents of the sea to the north of Novaya Zemlya,[2] viz. a very *cold undercurrent* of 2·2° C. (at 200 m.) coming from the east or from the "inner Arctic Sea" during the winter months from October to June, and a *warmer under-*

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[1] See the charts of the Willem Barents Expeditions, l. c.

[2] C. Weyprecht, 'Tiefsee-Temperatur-Beobachtungen im Ost-Spitzbergischen Meere, 1871–1874,' Petermann's Mitteilungen, vol. 24, 1878, p. 352.

current, with temperatures of —1·1° C. at 310 m. and —1·5° C. at 200 m., coming from the Atlantic Ocean during the three summer months, July, August and September. But Weyprecht's observations were unfortunately chiefly made with the Miller-Casella Minimum and Maximum Thermometer, and this instrument may easily give erroneous results in seas where there are several layers with several maxima and minima situated one above another, such as was probably the case in the sea explored by the Tegetthof Expedition. This instrument will also naturally have a tendency to give especially the lowest temperatures, the minima of the whole water-column examined during the summer when the temperature of the air is above zero, and the highest temperatures of the strata during the winter, when the atmosphere is cold.

If, however, Weyprecht's assumption of a seasonal change such as this in the under-current be correct — which I consider to some extent probable — his explanation that the cold under-current in summer comes from the inner Arctic Ocean is not supported by our observations in the North Polar Basin (see later), as we observed no water with such low temperatures. I should rather expect Weyprecht's cold under-current to come from the Kara Sea.[1] His explanation that the changes in the under-current would be caused by the pouring of the melted snow of the surrounding lands (especially Siberia) through the rivers into the Arctic Basin in the spring and summer, seems also somewhat doubtful. I think such an explanation might be quite satisfactory for surface-currents, but I doubt whether in this way great changes would be caused at depths of 300 m. or 345 m. It may be, however, that the prevailing winds have some similar influence, for chiefly during the winter and spring, they cause ice and surface water to be carried out of the North Polar Basin, and this will then naturally cause an increased indraught of Atlantic water underneath, which may again tend to retard the under-current running westward, north of Novaya Zemlya.[2] But even this cannot be of much importance for depths of 300 m. There is a third circumstance, however, which may be of more

[1] Cf. l. c., p. 353.

[2] Mohn's explanation (l. c., p. 193) that it would be the southerly and south-easterly winds prevailing in this sea during the winter, which produced a warmer bottom-current from the south, and the northerly winds prevailing during the summer, which produced a cold bottom-current from the Siberian Sea, seems to me doubtful. I should rather expect surface-currents, increased by the winds, in a sea like that to the north of Novaya Zemlya, to produce an increased under-current in the opposite direction along the bottom, and *vice versa*.

importance. During the winter, the water of the Kara Sea, or rather the sea to the north of Novaya Zemlya, is much cooled down by radiation of heat from the surface, and a sinking of the water towards the bottom is probably produced, as the vertical distribution of the salinity seems to be more uniform there than in the North Polar Basin. Favourable conditions for an increased indraught of warmer water from the south may thus arise during the winter, while the out-flowing, cold bottom-current will not have reached its full development before the end of the winter, in June. The out-flowing bottom-current will always exist, but during the winter it will consist of the slightly warmer water that was near the surface of the sea farther east during the previous summer, and during the summer it will consist of the somewhat colder water cooled down near the sea-surface to the east during the previous winter.

All this is, however, merely speculation. It would be of great interest to have this sea thoroughly explored, summer and winter, by a new Tegetthoff Expedition well equipped with modern instruments, and drifting with the ice. Judging from the observations at hand, it seems at any rate as if the conditions in the Kara Sea and the sea to the north of Novaya Zemlya are more or less different from those found by us in the North Polar Basin; and I consider it probable that the depths of the two basins are separated by submarine ridges at any rate to some extent, for otherwise there would be a more active influx of polar water from the North Polar Basin into the Kara Sea.

The coast water. The cold Lütke Current, at any rate during the summer, is kept away from the coast of Novaya Zemlya by the warmer and lighter coast-water, a fact which is demonstrated in our Section I, Pl. V, where the temperature of the water is seen to rise towards Goose Land, while the salinity decreases. This coast-water, which is evidently formed by the admixture of fresh water from the land as well as from the Russian rivers to the south (*e. g.* the Pechora), has, on account of its low density, a tendency to spread seaward over the heavier water. That its high temperature and low salinity near the surface are actually due to the admixture of water from the land, is apparent from some interesting observations by Middendorf himself, who at Kostin Shar on Novaya Zemlya (about 71° N. Lat.), on July 24th, 1870, found the temperature of the water of a broad brook to be

13·9° C. near its outlet into the sea. Higher up where the brook was abundantly fed by some considerable snow-drifts, the temperature of the water was still above 10° C., and in some shallow lakes from which the brook received contributions, he observed similar temperatures. This proves what an amount of heat is absorbed by the dark soil and the mountain sides during the polar summer, when the sun is above the horizon day and night. Along the coasts where the water is shallow, much heat may also be absorbed in a similar manner by the dark sea-bottom. Thus the rise of temperature in the uppermost strata of the sea, simultaneous with a fall in salinity, towards the coasts of the Murman and southern Barents Sea, is easily explained. The distribution of this warm coast-water (cf. above, p. 261) is seen in the chart, Pl. II, *e. g.* at Kanin Nos, Kolguyev Island, north of the Pechora River, Yugor Strait, Vaigach, Goose Land, and also farther north along the west coast of Novaya Zemlya; and it is also very prominent in Sections I, (on both sides), II, III and IV (at both ends). It was in layers of this coast-water that we observed the high temperatures of 8·4° C. and 7·5° C. on the sea-surface between our Station 5 and Yugor Strait, even quite near to drifting ice. It was also in the same coast-water along the Novaya Zemlyan coast that the Vega sailed south-east, and observed temperatures of 9·4° C. and 8·2° C., concealing from Pettersson the existence of the cold Lütke Current underneath. I have above, on p. 268, quoted some observations by Knipowitch made to the north of our Station 4, which prove the presence of the same coast-water, with rising temperature and falling salinity, farther north towards the Novaya Zemlyan coast. The distance of its outer boundary from land seems, however, to decrease towards the north. The high temperatures of this coast-water are not, as we have seen, directly due to water from the Gulf Stream, which does not directly reach the shore during the summer. But the presence of the water from this current in the sea outside is naturally of importance, as it makes the climate of these regions milder, and consequently the lands less arctic, than they would otherwise have been.

It is evident that at those times when the layer of this coast-water increases so much in thickness, that the density of the surface-layers of the sea becomes much lower along the west coast of Novaya Zemlya than in the Kara Sea, eastward-flowing surface-currents may be formed through the Kara Strait, as observed by Krusenstern in 1860 (see Pettersson, l. c., p. 348) and

Sidoroff in 1869 (Petermanns Mitteilungen, 1870, p. 453); while at other times the surface-currents run in the opposite direction, carrying ice eastward. It is evidently also this coast-water, and not the Gulf Stream, which occasionally causes a similar eastward-flowing surface-current through the Matochkin Shar, as observed by Nordenskiöld in 1875; whilst in other years, *e. g.* in 1881 (the observations of the Dutch Willem Barents Expedition), the conditions were very different.

In Yugor Strait the direction of the currents changed with the tide while we were there from July 29th to August 4th, 1893, in a way similar to that observed by previous travellers. The chief reason why this strait is kept more open for navigation than the Kara Strait is evidently that under ordinary circumstances continuous currents, carrying tightly packed ice-masses into it, are never formed through this narrow and shallow strait, and thus the ice-masses from the east do not as a rule enter the strait, except in the form of scattered floes.

The cold bottom-water. I have already (pp. 264, 265) mentioned how rapidly the temperature, especially of the deeper strata, sinks towards the east in the Murman and Barents Sea, and that we evidently have a current of cold polar water creeping westward along the bottom.

Mohn's Chart[1] of the bottom-temperatures (l. c., Pl. XXV) also demonstrates this feature clearly, and is on the whole in fair accordance with our observations, which gave bottom-temperatures below zero Centigrade, and generally below —1° C. east of our Station 1. To the north of our route, in latitudes 73° N. and 74° N., the bottom-isotherms of 0° C., and still more of —1° C., make great curves eastward. The reason is evidently that the water of the Gulf Stream has freer access in this direction along the bottom of the deep depression of the Barents Sea, while in the direction of our route it is greatly hindered by the configuration of the bottom, there being a shallow ridge in 35° and 36° E. Long. (cf. above, p. 260), which on the other hand also stops the cold polar water coming from the east. To the east of this ridge, there are also other ridges with still shallower water (see chart, Pl. III). By the above-mentioned eastward curve of the isotherms in about 74° N.

[1] See also Mohn, l. c., p. 184.

Lat. the cold bottom-water of the Barents and Murman Sea is, as it were, divided into two portions — the *northern cold bottom-water* of the Barents Sea, south-east of Spitsbergen and south of Franz Josef Land, and the *southern cold bottom-water* along the west coast of Novaya Zemlya, and covering the bottom of the south-eastern part of the Barents Sea, and the eastern part of the Murman Sea. I take it for granted that the *northern bottom-water* comes from the Sea to the north, north-east, and east. The *southern bottom-water* has, however, in my opinion, two or three sources. The greater portion comes probably from the Lütke Current through the Kara Strait, and along the before-mentioned submerged valley. But another addition may perhaps be received from a bottom-current from the north-east along the coast of Novaya Zemlya, also carrying water from the Kara Sea. A third source of the cold bottom-water, especially that found in the shallow sea near the coasts, may be the surface of the sea itself, during the winter. We have unfortunately no observations of the vertical or horizontal distribution of temperature and salinity in this sea in the winter; but I consider it highly probable that the water of the sea-surface in the neighbourhood of the coasts, has a considerably higher salinity at the end of the winter than during the summer, for the water is then less diluted by the admixture of fresh water from the rivers and the land, and its salinity is on the other hand increased by the formation of ice on the surface. Thus it is not improbable that especially in the shallow parts of the Murman Sea, cold bottom-water with temperatures of about $-1{\cdot}5^0$ C. or $-1{\cdot}6^0$ C., and even lower, and salinities of say about 34 ‰ or more, may be formed during the winter.[1]

But where is the cold bottom-water with a temperature of about $-1{\cdot}7^0$ C. or $-1{\cdot}8^0$, and salinities of about 35 ‰ or even 35·28 ‰, formed. Prof. Pettersson explains the cold and salt water at the bottom of the Kara Sea as "an influx of water from the Arctic Ocean caused by the mechanical reaction of the surface water *in motion* upon the deeper layers".[2] This explanation is however

[1] Cf. the series of temperatures and water-samples taken by Mr. Wollebæk in May, 1900, pp. 261, 272.

[2] Pettersson, l. c., pp. 337, 341, 349. In this cold bottom-water, temperatures of from -2^0 C. to $-2{\cdot}4^0$ C. were repeatedly observed on the Vega Expedition. Pettersson states that the observations were made with Ekman's insulated water-bottle, and an Åderman thermometer "of very elaborate workmanship" (l. c., p. 327). As the temperature of the atmosphere at that time, August 2nd, 1878, was probably several degrees

hardly satisfactory, seeing that the coldest water observed by us in the North Polar Basin was found at about 60 m., where the temperature might sink as low as —1·90° C.; but the salinity of this cold water never exceeded 34 ‰. The possibility that the cold, heavy bottom-water of the Kara, Barents, and Murman Seas may have been formed in the North Polar Basin seems thus to be excluded. It does not, however, seem more probable that the cold water with this high salinity of 34·9 ‰ and 35 ‰ arises from the surface of the southern parts of these seas themselves. The uppermost strata of the Kara Sea have much lower salinities, and this is also the case in the Murman Sea at any rate during the summer; and it is hardly probable that the salinity of the surface of these seas would rise so much during the winter. Nor do I consider it probable that the ice, unless quite exceptionally, attains such thicknesses that it might reach down to water-strata with such high salinities, and cool them down to such low temperatures.

The brine formed in the ice while freezing, assumes very low temperatures,[1] but I do not consider it probable that this brine, which is formed quite gradually, would, under ordinary circumstances, be able to sink down to the bottom of the sea through the much lighter water of the upper strata,[2] without being mixed with them, and gradually absorbed. Our observations in the North Polar Basin seem to contradict such an assumption (see later).

Perhaps the series of observations taken by Wollebæk on May 31st, 1900, in 71° 48′ N. Lat., 49° 38′ E. Long., which is given above on p. 272, may give us the explanation.

We see that in this region the sea-water of nearly 35 ‰ reaches the sea-surface at the end of the winter, in May. I consider it very probable that farther north in the sea to the north of Novaya Zemlya, this is also the case during the winter, as the water of the Gulf Stream is forced in this direction (cf. above, p. 262). The necessary conditions for the formation of very cold water with comparatively high salinities will thus be amply present during the whole winter. The water cooled down at the surface will gradually sink

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above 0° C., I do not see how these temperature-readings could possibly be too low; but it is an interesting fact that during the whole voyage of the Fram, we never observed at any depth of the North Polar Basin, a temperature below —1·9° C.

[1] In brine in holes in the ice, I have observed temperatures of —20·0° C.

[2] Prof. Pettersson believes, however, that he has proved that this may, occasionally at least, happen in the Polar Sea.

towards the bottom in a sea of such uniform salinity, and will to some extent be replaced by water from below. The final result will be that the whole sea, from the surface to the bottom, will be cooled down to temperatures near —2° C. as actually found by Weyprecht (cf. above, p. 275), and as we find to some extent at Wollebæk's station.[1] Some portion of the cold bottom-water thus formed will flow eastward north of Novaya Zemlya and southward along the submarine channel east of Novaya Zemlya, and fill the deep depression of the Kara Sea. From the Kara Sea it may again flow westward through the Kara Strait, and form the Lütke bottom-current into the Murman and Barents Sea, as mentioned before. But the cold bottom-water formed in the north-eastern part of the Barents Sea may also form a westward-creeping bottom-current through the Northern Barents Sea towards South Cape in Spitsbergen, south of which it may reach the bottom of the Norwegian Sea. Another bottom-current may also be formed which flows south-west along the west coast of Novaya Zemlya towards Wollebæk's station on May 31st, 1900, and our Station 3, where it will meet the cold Lütke Current through the submerged Novaya Zemlya Channel. The united masses of cold bottom-water thus produced will, however, during their farther course westward along the bottom of this shallow sea, gradually be mixed with the water of the warmer current running in the opposite direction near the surface. The result will be that the temperature of the latter will be gradually lowered towards the east, while the temperature of the bottom-water will be much increased towards the west. This intermixture will naturally be most active along the fjord-like depression in the sea in about 73° and 74° N. Lat., where the Gulf Stream has freer access (see above, p. 279); and the warm bottom isotherms will therefore go farthest east in this region.

The cold bottom-water of the Barents Sea has a great resemblance to the cold bottom-water (below 800 m.) of the Norwegian Sea; it has a still lower temperature, and very much the same salinity, the salinity of the latter being, according to my determination, about 35·05 ‰ everywhere below 800 m.

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[1] Where the sea-surface has a very high salinity (35·2 ‰), very cold and heavy water may be formed, and this will naturally, where it occurs, form the lowest strata of the sea. The formation of heavy water in such a sea may also be assisted by the brine arising during the formation of ice on the surface.

According to Sections VII and VIII, Pl. V, and Mohn's chart of the bottom-temperatures (l. c., Pl. XXV), however, it does not seem probable that the cold bottom-water of the Barents Sea, under ordinary circumstances, can have much communication with the Norwegian Sea, except perhaps through the narrow channel between Bear Island and Spitsbergen. But we know nothing of the conditions during the winter, and there may also be variation in the currents of this part of the Ocean, from one year to another.

The densities, $S\,\frac{t}{4^\circ\,\mathrm{C.}}$, *and pressure.* If the densities of the water *in situ* be introduced in our sections instead of the temperature and salinity, and we draw the isopyknals (lines of equal density) as shown in the sections on Pl. VI, we get a clear representation of the direction in which the distribution of unequal density, or unequal pressure, will tend to carry the water, and we might in this manner, if we had sufficient observations, obtain the material for calculating the quantities or the accelerations of the forces to which the water is thus exposed, not considering the effect of the winds upon the surface of the sea.

We see that according to the sections on Pl. VI, the distribution of the densities will tend to produce currents at the several depths in almost exactly those directions, as our above discussion of the distribution of temperature and salinity leads us to assume. In section I, Pl. VI, the isopyknals for densities lower than 1·0272 incline fairly steeply towards land east of Station 3. The isopyknals of 1·0274 and 1·0276 also incline towards the east, although more gently, from near the sea-surface at Mohn's Station 264, to a depth of about 30 m. or 35 m., near the coast of Novaya Zemlya; there is only a slight elevation of the lines at Station 3. The isopyknal of 1·0278 is situated almost horizontally at a depth of 40 m. with a slight elevation at Station 3, while the isopyknal of 1·0280 inclines steeply downward both towards the east and west from about 40 m. at Station 3.

We have thus, (1) near the surface a wedge of light water, with densities below 1·0274, which is deepest—30 to 35 metres thick—in the eastern part of the sea (Stat. 4), but tapers off towards the west to 0 m. at Mohn's St. 264. In this light water there is evidently, with an exception at St. 1, a

strong tendency to spread westward, as indicated by the arrows. Near the coast of Norway, there is probably a similar smaller wedge of light surface-water with a tendency to spread eastward[1]; (2) below the light surface-water, a wedge of heavier water with densities between 1·0274 and 1·0280, which is deepest in the western part of the sea, perhaps from 150 m. to 200 m. or more thick, and tapering off towards the east, between the light surface-water and the heavy bottom-water, to about 30 m. thickness at St. 3. Farther east towards land, it again increases somewhat in thickness. It is evident that in the western part of this wedge of water, the force is directed eastward (see the arrows) both above and below the nearly horizontal isopyknal of 1·0278, and a current of Gulf Stream water is thus produced in this direction; but near St. 3, this current seems to be stopped, at any rate partly, by the pressure exerted in the opposite direction; (3) the cold, heavy bottom-water with densities of about 1·0280 is driven by the pressure westward along the bottom from St. 3, as indicated by the large arrow. It is also to some extent driven eastward from St. 3 towards Novaya Zemlya (see the small arrow). The course and velocity of this bottom-current must, however, to a great extent be influenced by the configuration of the bottom. The several ridges and depressions evidently have a retarding or accumulating effect upon its westward course (see chart, Pl. III, and Section I), and explain the rapid rise of temperature in that direction.

Section II, Pl. VI, demonstrates how the light surface-water, the coast-water, has a strong tendency to spread over the sea-surface northward from the Russian coast, while the heavier, underlying water has a tendency in the opposite direction. If the light surface-water be carried away northward (*e. g.* by winds) more rapidly than the fresh supply from land warrants, the heavy bottom-water will naturally rise along the coasts; if the reverse be the case, the upper boundary of the bottom-water will be depressed.

In Section V, Pl. VI, the pressure has, on the whole, a tendency, both near the surface and in deeper strata, to carry the water towards the

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[1] It is not of course therefore certain that surface-currents in the above-mentioned directions are formed. If for instance the lighter surface-water moves in the same direction, but with a greater velocity than, the deeper water, and perhaps also than the heavier surface-water to the left, it will, on account of the Earths rotation, have a tendency to keep on the right side of the current, and thus the tendency to spread over the heavier water may be more or less checked.

north-west, from our Stations 6 and 5 towards St. 3 (see the arrows). At 15 or 20 m. the force seems to have an opposite direction between Sts. 3 and 5.

The isopyknals of Section VIII, Pl, VI (across the entrance to the Barents Sea) demonstrate a very strong tendency of the warmer water, in the southern portion of the section, near Norway, to spread northward over the heavier water to the north. But this tendency may to some great extent be checked by the Earth's rotation, as the water near the surface probably flows eastward with a greater velocity than the deeper water, and it may also be that the lighter water flows parallel to the Norwegian coast with a greater velocity than the heavier water farther from land. If the effect of the forces be calculated according to Prof. *V. Bjerknes's* theory,[1] and by the methods invented by *Bjerknes* and Mr. *Sandström*,[2] we find that in the section between Station 57 and the Norwegian coast, and between 0 m. and 200 m. there are 7500 solenoids (*c. g. s.*), which would make the water of this section circulate (*i. e.* flow from the coast near the surface, and towards the coast at 200 m.) with a mean acceleration of 40 cm. per second every 24 hours, the friction of the water not being considered. If, however, the water at the surface of the sea flows eastward with a velocity which is greater by 7 cm. per second (= 6000 m. in 24 hours) than the velocity of the water at 200 m., this difference, on account of the Earth's rotation, is sufficient to check the effect of the force with the above acceleration, and will keep the light water in position on the right side of the current.[3]

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[1] *V. Bjerknes*, 'Videnskabsselskabets Skrifter', Christiania, 1898. *Idem*. K. Svenska Vet.-Akad. Handl. vol. 31, No. 4, Stockholm, 1898. See also 'Meteorologische Zeitschrift', 1900.

[2] A description of this method will shortly be published.

[3] Mr. *Walfrid Ekman* has had the great kindness to make the above calculations. I take this opportunity of offering him my sincere thanks for this and other valuable services.

III.

THE KARA SEA AND THE SIBERIAN SEA.

When we passed through the Kara Sea in the beginning of August, 1893, the ice-conditions were not favorable. The Kara Strait was probably filled with ice, judging from the drifting ice that we met with in Pechora Bay (see above, p. 273). The edge of the pack-ice was situated only some few miles east of the eastern entrance to the Yugor Strait, leaving a channel of open coast-water, only some few miles broad, along the coast towards the south-east, in which the Fram had to sail towards the Gulf of Kara, where she turned northward along the west coast of Yalmal, but was stopped for several days — August 6th to 9th — by ice which lay close up to the land. More or less scattered ice, partly with big floes occurred northward along the coast until August 12th, 1893, just south of the Malygin Strait, in about 72° 50′ N. Lat., 68° 35′ E. Long., north of which the sea was open, with no ice in sight (see Table of surface-temperatures, p. 70). The surface-current was observed on a few occasions to go north along the west coast of Yalmal. The ice observed by us in this southern part of the Kara Sea was partly composed of fairly heavy floes and hummocks, which were, however, much corroded by melting. The ice seemed nowhere to be very compact, as the sky on the horizon behind even apparently tight ice, *e. g.* east of Yugor Strait, always had a bluish colour, indicating much open water between the floes; it never had the whitish colour that it generally has over tight ice-fields. I think it is doubtful whether the whole sea between Yalmal and Novaya Zemlya was covered with ice, and I consider it more probable

that the ice was distributed chiefly as a broad belt along the coasts, carried by the current from the north along the east coast of Novaya Zemlya, and towards the west coast of Yalmal, whence it was again carried northward until it met with the current from the east through the Malygin Strait, south of Beli Ostrov (White Island),[1] and was probably again carried in a more westerly direction, the sea to the north being covered with light water from the Obi River, pressing westward over the heavier water to the west, and thus carrying the ice in that direction. The ice may thus be kept by a kind of eddy in the southern part of the Kara Sea. This ice, however, in most places during the summer, is kept from actually touching the coast, by the water from the land and the rivers, which, as before mentioned (p. 277), has a strong tendency to spread seawards over the heavier sea-water, thus forming an open lane along the coasts. Along the Yalmal Coast, northward to the Malygin Strait, there are, however, but few rivers and little land-water, and the coast-lane was therefore here less developed.

The ice-conditions seem, however, to change rapidly in the Kara Sea; for only a few weeks after our passage, British vessels going from the Yugor Strait to the Yenisei River found the sea perfectly open for navigation, and met with hardly any ice, as far as I know. It seems astonishing that such masses of ice as we saw, could disappear by melting in such a short time. This nevertheless seems to have been the case, to a great extent at least, as it is not probable that the ice could have been carried northward by winds, for to the north we had prevailing north-easterly winds during almost the whole month of August.

It is probable that the ice would melt most rapidly near the coasts, where the water from the land and the rivers carries a continuous fresh supply of heat into the sea, and where, on the other hand, the atmosphere is also warmer, being heated by the dark surface of the land, which absorbs much heat during the arctic summer (see above, p. 277).

It is thus natural that the ice should remain longest in the middle of the Kara Sea, as maintained by Prof. Pettersson, as well as towards the Yalmal Coast; and this would not be due to the presence of cold water

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[1] It is noteworthy that just in this same latitude west of Beli Ostrov, the Vega met with "vast floes of drift-ice" (see Pettersson, l. c., p. 340), although no ice was seen elsewhere in the Kara Sea.

underneath the sea-surface alone. But the distribution of the ice is chiefly dependent upon the wind and the surface-currents. Thus the ice north of 73° and 74° N. Lat. is driven westward by the Obi and Yenisei waters towards the east coast of Novaya Zemlya, while farther south it may often be carried towards the Yalmal coast. Pettersson is undoubtedly right (l. c., p. 340) when he maintains that the cold underlying water has a retarding influence upon the ice-melting; but he seems to ascribe to this underlying water too much influence upon the distribution of the ice in the sea, and he has evidently not quite realized the great effect of winds and surface-currents in this respect, and the velocities with which the ice may travel.

As we sailed chiefly in the shallow coast-water along the shores of the Kara Sea, and as, being rather late, we were always much pressed for time during the whole voyage along the Siberian coast, there was no opportunity for doing much oceanographical work of any importance during that part of the voyage.

Only on one occasion, on August 11th, 1893, did we take a series of temperatures and water-samples off the Yalmal coast (see Table, Station 7, p. 245). This one series in the shallow water of 26·5 m. shows, however, that the water of the Kara Sea is different from that of the North Polar Basin, having a salinity of 32·60 ‰, and a temperature of —1·09° C. at 24 m., while we never found the temperature above —1·6° C., and the salinity was generally lower, at similar depths in the North Polar Basin. The water at Station 7, however, is also decidedly different from the water at Station 6 in the Murman Sea west of Yugor Strait, which was much colder, and had higher salinities at similar depths. The latter water evidently resembles more the water of the western part of the Kara Sea, while the water at Station 7 has more resemblance to the uppermost strata of the western part of the North Polar Basin. I have, however, already (pp. 277, 280) pointed out that the water of the Kara Sea, especially in its deeper strata, is decidedly different from that of the North Polar Basin, and that probably the latter is separated from the deep basin of the Kara Sea by some submarine ridge or plateau; for the water at the bottom, or at about 120 m., in the Kara Sea, as well as at our Station 3 in the Barents Sea, has such a much higher density (about 1·02810) than the water at similar depths of the North Polar Basin (about 1·02760), that it could not but be carried by its weight out into the latter, and be

replaced by polar water, if there were an open communication between the two. The water farther north-east near Cape Chelyuskin, however, according to the observations on board the Vega and the Fram, is much more like the water of the North Polar Basin. For instance, on the surface of the sea near Cape Chelyuskin, we found salinities of from about 26 ‰ to 30 ‰, and temperatures of from —1° C. to —1·6° C.

The Vega Expedition found, just east of Cape Chelyuskin,[1]

	Depth in m.	0 m.	10 m.	50 m.	100 m.	128 m.
In 77° 39′ N. Lat. 105 7 E. Long.	Temp. ° C.	0·0	—1·4			—1·2
	Sal. ‰	28·4	32·6			34·5
In 77° 24′ N. Lat. 108 20 E. Long.	Temp. ° C.	0·5		—1·2	—1·4	
	Sal. ‰	27·6		33·9	34·0	

These temperatures and salinities are much more like those found by us at similar depths in the North Polar Basin, than those found by the Vega Expedition in the Kara Sea (see above, p. 274). I consider it therefore probable that the deep sea just east of Cape Chelyuskin, is simply a part of the deep North Polar Basin discovered by us to the north, which here approaches the otherwise shallow Siberian coast. But this deep sea is evidently, as before mentioned, separated from the deep basin in the western part of the Kara Sea (along the east coast of Novaya Zemlya) by a shallow submarine plateau or ridge, probably extending from the Western Taimur Peninsula to Franz Josef Land. Ensomheden (Lonely Island) and the Nordenskiöld Group, discovered by us, and extending north from Taimur Island, are probably situated on this plateau.[2]

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[1] See Pettersson, l. c., pp. 357, 365, and Section V, Pl. 24.

[2] Pettersson was of opinion (l. c., p. 359) that the deep sea east of Cape Chelyuskin is in communication with the deep basin of the Kara Sea, as he thought the temperatures and salinities at the bottom of these Seas were "almost identical". But this view, which is evidently due to the imperfect knowledge at that time of the distribution of temperature and salinity in the Ocean, is decidedly untenable with our present knowledge; we should now call a difference in temperature such as that between —1·3° C. and —1·8° C. and still more a difference in salinity such as that between 34·5 ‰ and 34·9 ‰ at the bottom of the sea, very considerable.

The Observations of the temperature and salinity at the surface of the sea along the Siberian Coast are given in the tables on pp. 66 *et seq.*, 158 *et seq.*, and on the charts, Pls. VII to IX. Our temperatures were, upon the whole, much lower than those observed in the same sea, and at the same season of the year, during the Vega Expedition, from August 1st to 28th, 1878. This circumstance is, however, easily accounted for by the presence of much more ice in this sea in August and September, 1893, than in August, 1878. But at the same time we observed, upon the whole, much higher salinities in the water of the sea-surface. This may perhaps indicate that there was a smaller amount of coast-water in the summer of 1893 than in 1878. It may be that the Siberian rivers had carried less fresh water into the sea.[1] It may also be that from this same cause there was less warm, light coast-water to keep the ice away from the coast (see above, p. 286), and to accelerate the melting of the ice. It is noteworthy that whereas Nordenskiöld visited Actinia Bay on Taimur Island, and passed the sound north of that island during the days from the 14th to the 18th August, 1878, almost without meeting a single ice-floe, we found Actinia Bay, as well as the sounds between the islands to the north, completely covered with unbroken ice, in the beginning of September, 1893; and it was not until September 5th, that the ice was at last broken up and swept away by a south-westerly storm.

The difference between the Vega observations and ours is also very striking, for example, in the sea just north and north-west of the mouth of the Yenisei River. While Nordenskiöld observed there, on the 10th and 11th August, 1878, surface-temperatures of about 7° C. and 8° C., and salinities of from about 9 ‰ to 11 ‰, we observed at the surface of the same sea, on the 18th and 19th August, 1893, temperatures of from 0° C. to 2° C., and salinities from 15 ‰ to 23·7 ‰ (see Table, p. 158).[2] The cause of this striking difference may, however, to some extent be that we had much, and fairly strong, north-easterly winds during the preceding days (see Table, p. 71, fifth column), which had partly carried the light surface-water from the Yenisei

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[1] This might be due either to less precipitation over Siberia during the previous winter, and consequently less snow, or to a colder spring and summer.

[2] Pettersson's Section III (l. c., Pl. 24) from Port Dickson along the Vega's route to Actinia Bay, also indicates that this sea was to a great extent filled with water of a higher temperature and lower salinity in August, 1878, than in August, 1893, especially in its southern part.

westward, and partly stirred the sea and mixed the surface-layers with the underlying water. This effect of the wind is distinctly seen in our observations made while we were at anchor near Renø, one of the Kjellman Islands. On the evening of the 20th August, 1893, we had there very fresh surface-water of 2·9° C. and 4·68 ‰. The wind was then from the north, with a velocity of about 5 metres per second (see Table, p. 71). Next morning (August 21st), the wind began to blow more strongly from the NE., and in the afternoon its velocity even increased to 12 m. The temperature of the sea-surface sank immediately, first to 1·5° C. and then to 0·9° C. The salinity increased simultaneously, although not so abruptly; at noon on August 21st, it was 6·47 ‰, but the next day, August 22nd, at 8 p. m. it had increased to 22·07 ‰. A current was constantly running southward through the sound in which we were at anchor, but the velocity of this current increased much with the wind on the 21st August, and amounted to several knots in the afternoon, so that we could not row against it in the middle of the sound.[1] This stronger current evidently brought in the surface-water with the much higher salinity, which we continually found during the subsequent days, from the sea in the north-east and the current prevented the coast-water from the south, from the Pyasina River or from some unknown river on the continent, to spread northward over the heavier sea-water. The current upon the whole, flowed continuously towards the south-west, when we sailed along this part of the coast, between Dickson Island and the Nordenskiöld Group; but this was evidently due to the continuous north-easterly winds which we had from August 12th to 27th, 1893.

Off Taimur Island and at Cape Lapteff, from August 29th to September 2nd, we again had very low salinities at the sea-surface, decreasing from about 10 ‰ to 4·6 ‰, with temperatures about zero Centigrade, or a little below. We had at that time very little wind, and the ice on the sea-surface was melting rapidly, forming a surface-layer, between 2 and 3 m. deep, of nearly fresh ice-water in which the Fram made very slow progress, on account of the 'dead-water' waves formed.[2]

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[1] See all our difficulties with this current in 'Fram over Polhavet,' vol. I, p. 139, or 'Farthest North' vol. I, p. 160.

[2] This strange and highly interesting phenomenon will form the subject of a special Memoir by Prof. V. Bjerknes and W. Ekman later in this report. See also 'Fram over Polhavet', vol. I, p. 133, and 'Farthest North', vol. I, pp. 173, 174, 177.

At Archer Harbour, in Taimur Sound, the temperature of the sea-surface was from about —0·2° C. to —0·4° C. on September 3rd and 4th, and the salinities were about 8 ‰. On these days there seemed to be regularly changing tidal currents through the sound. But on the morning of September 5th, a strong south-westerly gale began to blow, bringing much ice into the sound from the west (see Table, p. 74), and the temperature sank immediately to —0·75° C. at 8 a. m. and —1·2° C. at noon, while the salinity increased to 16·94 ‰ at 8 a. m. and 24·85 ‰ at noon. During that afternoon and the following day, the temperature sank and the salinity increased still more. The changes were consequently quite similar to those observed during the north-easterly gale in the sounds between the Kjellman Islands.

In Taimur Bay we again met with somewhat lower salinities at the sea-surface, which may have been due to water coming from the Taimur River; but our surface-salinities were considerably higher, and our temperatures lower, than those observed by the Vega Expedition on August 18th, 1878, although we passed farther south and nearer to the land; but we also met with much more ice, which extended much farther south. Nordenskiöld found 10·1 ‰ with 2·6° C., and 12·0 ‰ with 1·6° C., while we observed 20·17 ‰ with —1·0° C. in Taimur Bay, (on September 7th, at 8 a. m.). Just off the extremity of the King Oscar Peninsula, we passed through a belt of brown surface-water running northward, and evidently coming from some river to the south. The salinity of this surface-water was only 6·08 ‰, and the temperature 0·6° C. In Toll Bay (Sept. 7th and 8th), where we were moored to an ice-floe, with ice round us, and where there was a river-estuary very near us, we observed fairly low salinities, about 15 ‰ (with temperature from about —0·4° C. to —0·9° C.).

But during our northward voyage (on September 9th), and round Cape Chelyuskin, we again observed much higher surface-salinities — from 25·6 ‰ to 28·9 ‰ — which were very similar to those observed during the Vega Expedition in the same sea, but upon the whole somewhat higher, the only exceptions to this being just north of Cape Chelyuskin and east of it, where we had lower salinities than the Vega. The explanation of this may be that when we passed there was a current running westward, carrying coast-water from Thaddeus Bay. But even at this place we found somewhat lower surface-temperatures (—1·1° C.). Our surface-temperatures and salinities observed

in this northern part of the Siberian Sea are very similar to those observed by us farther north in the North Polar Basin, and it is evidently the same water. The assumption that such is the case seems also to be confirmed by the soundings made during the Vega Expedition to the east of Cape Chelyuskin, as mentioned above (p. 288).

Just west of Cape Chelyuskin, or rather west of Cape Vega, on the evening of September 9th, 1893, we observed a strong current running towards the west or south-west along the coast; but I suppose this to have been a tidal current. East and south-east of Cape Chelyuskin, the surface-salinity again sank a little to 25·88 ‰ (Sept. 10th, 12 p. m.) outside Thaddeus Bay, where probably some river discharges its water into the sea; but eastward the salinity of the sea-surface again increased, and attained its maximum—above 30 ‰—with very low temperature—from −1·2° C. to −1·6° C.—off the north-east corner of the Eastern Taimur Peninsula, on September 11th and 12th (in about 76° N. Lat., 114° E. Long.). These salinities are very much higher, and the temperatures lower, than those observed on board the Vega on August 22nd and 23rd, 1878, in the same sea, although that vessel sailed farther from the coast, and was also in the ice. Our surface salinities and temperatures here are altogether similar to those observed at the surface of the North Polar Basin to the north-east, in April and May, 1894.

It is rather noteworthy, that while we observed our maximum of surface-salinity and minimum of surface-temperature during our voyage along the Siberian coast at this place, the maximum of salinity during the Vega Expedition was observed just off Cape Chelyuskin, but with no marked minimum of temperature. The Vega's minimum of surface-temperature (—1·0° C.) was, however, at about the same place as ours, without any maximum of salinity, while we had a secondary maximum of salinity (28·90 ‰) just west of Cape Chelyuskin. The explanation may be that there was more coast-water in 1878 than in 1893, so that the surface-water at the north-eastern corner of the Taimur Peninsula was then more diluted with coast-water from the south; while this was not the case farther north in the sea off Cape Chelyuskin, where, on the contrary, the Vega's salinities were higher than ours, which had probably been reduced by a current of coast-water from Thaddeus Bay.

Southward along the eastern coast of the Taimur Peninsula, the surface-salinity decreased somewhat to about 24 ‰, while the temperature rose a

little to about —1° C. Just north of the entrance to Khatanga Bay, the salinity suddenly decreased, first to 19·07 ‰ and then to 16·38 ‰ and 15·85 ‰, while the temperature rose to —0·1° C. (Sept. 13th, 1893). Almost exactly in the same latitude (75° N.), but 40 miles nearer to the coast, the surface-salinities observed on board the Vega also decreased from 23·1 ‰ (with + 1·4° C.) to 14·3 ‰ (with + 4° C.) on August 24th, 1878. We have here a clear demonstration of the influence of the Khatanga waters.

During the Fram's southward and eastward course from Khatanga Bay, the salinity of the sea-surface remained upon the whole comparatively low, until it again increased considerably during the northward course west of the New Siberian Islands.

Prof. Pettersson maintains (l. c., p. 335) that the observations of the Vega Expedition along the Siberian coast prove the correctness of Nordenskiöld's theory that the northward-flowing surface-currents in the Kara Sea and the Siberian Sea, consisting of the water from the Siberian rivers, deviate considerably to the east along the coast, on account of the Earth's rotation. Our observations do not confirm this assumption, nor do I quite see that a general conclusion such as this can be drawn from the Vega observations, not, at least, so definitely as was done by Pettersson.

Wherever we had an opportunity of making direct observations of the surface-current in the Siberian Sea from Yalmal to the New Siberian Islands, we found the current running in the opposite direction, *i. e.* contrary to our course, except in Archer Harbour, where we observed regular tidal currents. That we actually, as a rule, had contrary currents during our voyage along the coast, is also proved by the fact that our dead reckoning was always, with only some few exceptions, in advance of the positions obtained by our astronomical observations. These contrary currents, especially along the coast from Dickson Island to Taimur Island, may, however, be explained by the frequent contrary winds we encountered during that time.

Our observations of the salinity and temperature of the sea-surface off the mouths of the Siberian rivers do not in any case prove with certainty the existence of any predominating eastward tendency in the surface-currents produced by the river-water. From our observations in the North Polar Basin, we now know that one general feature of this sea is that the salinity of the surface increases towards the north and north-west with the distance from

the Siberian coast, where great rivers fall into the sea, and this same feature we find along the coast itself. The salinity of the sea-surface is lowest, upon the whole, in the most southern parts of the eastern Kara Sea, and the Siberian Sea, near the mouths of the great Siberian rivers both west and east of the Taimur Peninsula, while the salinity increases and the temperature sinks northward both along the western and the eastern Taimur coast, as well as west of the New Siberian Islands. It is, however, true that the salinity increases most rapidly northward along the eastern Taimur coast. We also find exactly the same features in the Vega observations.

In the sea to the north of the estuaries of the Obi and Yenisei, I do not find, according to our observations or those of the Vega Expedition, that the river-water had spread much more over the sea-surface towards the north-east than towards the north-west and west. Just north-east of Dickson Island, we observed a salinity of 23·74 ‰ on the sea-surface, and the lower salinities of the coast-water towards the north-east owe their origin more probably to the Pyasina River and other rivers on the Taimur Peninsula, than to the water from the Yenisei. We must of course also expect to find lower salinities in the coast-water along the coast, than in the Kara Sea to the north-west of the Obi, where we are far from any coast; but nevertheless the salinities there too are low, as observed on board the Vega. In the Kara Sea between Yalmal and Novaya Zemlya, the salinities are higher upon the whole than along the Siberian coast and in the North Polar Basin as before mentioned, but there are other reasons for this (see p. 288).

In Taimur Bay the surface salinities were certainly no lower towards the coasts of the Chelyuskin Peninsula, than towards Taimur Island, either in our observations or in those of the Vega Expedition; if anything there was rather a tendency in the opposite direction. That the salinities were low at the King Oscar Peninsula and in Toll Bay is natural, as we were there close to the coast. We thus see that neither the Fram observations nor the Vega observations warrant Pettersson's assumption of a "great fresh-water current of the Kara Sea, derived from the Obi and Yenisei rivers" (l. c., p. 361) which should flow towards the north-east along the Siberian coast as far as Cape Chelyuskin.

East of the Taimur Peninsula, we regularly found minima of salinity, generally with maxima of temperature, outside the mouths of the great rivers, Khatanga, Anabara, Olenek, the western and the eastern main branches or

or distributaries of the Lena, at the western and eastern side of the delta. In the situation of these minima I can find no distinct indication of an eastward deviation of the currents from these rivers; on the contrary there is often a tendency in the opposite direction. I cannot agree with Pettersson that "it can be seen most unmistakably" (l. c., p. 361) from the Vega observations, that the currents from the above rivers have a distinct eastward deviation. Off the mouth of the Khatanga, our minimum of salinity, 15·85 ‰, with the maximum of temperature, —0·1°C., is situated just east of the northern entrance to Khatanga Bay, or a little more northerly. The Vega observations exhibit a similar minimum of salinity, 14·3 ‰, in 75° N. Lat., 113°33′ E. Long., just on the north side of the northern entrance to Khatanga Bay. S uth of this minimum, the salinity again increased to 15·0 ‰ and 15·2 ‰. South of the southern entrance to the bay, there was another minimum of 13·6 ‰ and 13·1 ‰, but the Vega was here so near to the coast, that we naturally expect the lower salinity of the coast-water. To the south the salinity again increased to 16·7 ‰, although the Vega continually sailed very near to the coast. In our observations there is no second minimum to be seen south of the southern entrance to Khatanga Bay, but the salinity naturally decreased — from 18·82 ‰ to 18·18 ‰ — when we approached the coast on September 14th, at 8 a. m. Southwards the salinity again increased until we approached the Anabara. The fact that the salinities of the sea-surface were higher, and the temperatures lower, to the north of Chatanga Bay than south of it, both in our observations and in the Vega observations, cannot be regarded as a proof that the river-current from the bay deviates to the right; for on the one hand, both the Vega and the Fram sailed nearer to the coast south of the bay than north of it, and we must consequently expect to find lower salinities with higher temperatures; and on the other hand, it is, upon the whole, quite natural that it should be so. As before stated, the salinity at the surface of the Siberian Sea and the North Polar Basin increased everywhere towards the north and north-west, and at this place in particular, we have great rivers to the south, which must necessarily be expected to dilute the sea-surface with their volumes of water, as they spread northward; while there are no rivers of any importance to the north along the eastern Taimur coast. We should therefore rather expect a northward-flowing current along this coast.

South of Khatanga Bay, our surface-salinity increased to 19·34 ‰ (with —0·5°C.), but in 73°49′ N. Lat., 114°7′ E. Long., to the north or north-west of the mouth of the Anabara River, it suddenly sank (Sept. 14th, 4 p. m.) to 16·29 ‰, and the temperature rose to 0·0°C. The surface-salinity and temperature now remained nearly unaltered for some distance during our eastward course north of this river, until the salinity again suddenly rose on the following morning (Sept. 15th, 8 a. m.) from 16.88 ‰ to 18·52 ‰ (in 73°55, N. Lat., and 116°51′ E. Long.), while the temperature remained about the same. We had then evidently crossed the current from the Anabara River, and this current certainly exhibits no further eastward deviation than the configuration of the coast on both sides of Anabara Bay renders necessary. The Anabara has, however, according to Baron von Toll's map, a more westerly situation than that shown on Nordenskiöld's chart (see Pettersson's paper, Pl. 25), its longitude being about 113° 30′ E. In the Vega observations we find, nearly in the same place, a distinct minimum of salinity of 12·8 ‰ and a temperature-maximum of 5·8°C. in 73°44′ N. Lat. and 113°53′ E. Long (Aug. 25, 1878, noon), probably just outside the mouth of the Anabara River; and there is hardly any indication of an eastward deviation of the river-current, for there were higher surface-salinities (17·8 ‰) towards the east than towards the north (16·7 ‰) from this place.

Farther east, our salinities of the sea-surface increased somewhat, but it is a noteworthy fact that simultaneously the surface-temperatures also rose, while during our previous voyage along the Siberian coast, we had almost always found that the surface-temperature sank with rising salinity, and *vice versa*. The explanation of the exception in this case may be that there was no ice in sight in this part of the sea (see Table, p. 76), although this circumstance does not always have much effect upon the temperature of the surface of this sea (*e. g.* cf. the temperatures from Sept. 17th to 20th, 1893, p. 77).

North of the Olenek River (Sept. 16th, 4 a. m.; 74°13′ N. Lat., 120°20′ E. Long.), there was a slight fall in the surface-salinity from 21·74 ‰ (with 2·0°C.) to 19·13 ‰ (with 1·8°C.); but farther to the north-east it again increased to 20·73 ‰ (with 1·9°C.) and 22.96 ‰ (with 1·55°C.). A little to the west of the longitude of our minimum there was a similar, but much more distinct minimum of salinity in the Vega observations, *viz.* 8·8 ‰ with 2·6°C. in

73° 41′ N. Lat., and 119° 13′ E. Long (Aug. 26, 1878, 8 a. m.),[1] east of which the salinity again increases to 11·1 ‰ and 11·9 ‰. It is evident that this minimum (of the Vega and the Fram) is caused by the current from the Olenek River, but according to Nordenskiöld's chart (see Pettersson, l. c., Pl. 25), the minimum is situated about two degrees west of the mouth of the Olenek, and should consequently indicate a westward deviation of the river-current. But according to Toll's latest map, the mouth of the Olenek River is situated nearly two degrees farther west than Nordenskiöld has it in about 120° 10′ E. Long.; and the minima of the Fram and the Vega observations are consequently situated due north of it. We thus see that we can almost determine the longitude of the mouth of these rivers by the aid of the minima of salinity at the sea-surface to the north of them.

After finding that the salinity of the sea-surface to the east of the longitude of the Olenek increased to 22·96 ‰ (with 1·55° C.), we found that it once more sank to 19·32 ‰ (with 0·9° C.), in 74° 34′ N. Lat., and 123° 21′ E. Long. (Sept. 16,4 p. m.), and farther east to 12·85 ‰ and 12·18 ‰ (with 0·6°) in 125° 25′ E. Long.). In almost exactly the same longitude, but farther to the south, we have, in the Vega observations, a very distinct minimum of salinity, 7·5 ‰, and a maximum of temperature, 3·8° C., in 73° 40′ N. Lat., and 123° 10′ E. Long. This is nearly due north of the mouth of the eastern main branch of the Lena (on its delta), which, according to Nordenskiöld's chart, is situated in 123° 40′ E. Long, but according to Toll's chart in about 122° 40′ E. Long. Farther east, to the north of the middle portion of the delta of the Lena, where no great branches of the river reach the sea, the Fram's salinities of the sea-surface increase to 16·62 ‰ with a temperature minimum of —0·4° C. in 131° 4′ E. Long. (75° 1′ N. Lat.) and the Vega's salinities to as much as 17·4 ‰ (with 2·8° C.) in 126° E. Long. (73° 50′ N. Lat.). Farther east, the surface salinities again decrease in the Fram observations to a minimum of 12·97 ‰ (with —0·08° C.) in 132° 47′ E. Long. (74° 38′ N. Lat.) and in the Vega observations to a minimum of 4·9 ‰, with a temperature maximum of 4·4° C., in 130° 20′ E. Long. (74° 9′ N. Lat.). In 128° 50′ E. Long. the salinity had already sunk from 12·3 ‰

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[1] It is strange that both in the Vega observations and the Fram observations, the temperature of the sea-surface at this place sinks towards the east, even with decreasing salinity.

to 7·4 o/oo, and the temperature had risen from 2·4° C. to 4·2° C. According to Toll's chart, the longitude of the actual minimum should be a little east of the longitude of the entrance to the eastern estuary or the main mouth of the Lena River, which is situated in 129° 30′ E. Long. It might thus seem as if we here actually had a slight deviation of the current from the Lena towards the east; but this deviation is easily explained by the fact that the main branch of the Lena flows into the sea in an eastward direction.

To the east of this minimum of surface salinity the Vega observations once more show increasing salinities eastwards, with no distinct minimum for the Yana River. The explanation of this may be that the eastward-flowing fresh water from the eastern branch of the Lena, and the northward-flowing water from the Yana, meet in the bay east of the delta of the Lena, where they unite to form the surface-current with low salinities of 4·9 ‰ to 9·1 ‰, crossed by the Vega between 128° 50′ E. Long. (7·4 ‰) and 135° 35′ E. Long. (9·1 ‰). The fact that the salinities were low, on the whole, along the coast eastward, does not prove any eastward current of Lena water along this coast; for on the one hand, there are several great rivers, *e. g.* the Yana, the Indigirka, etc., which will naturally diminish the salinity of the coast-water at their mouths, and on the other hand, the salinities of the sea-surface can hardly be said to be lower to the east of the delta of the Lena, than westward between it and Khatanga Bay.

We thus see that *neither our observations, nor those of the Vega Expedition, prove any distinct eastward course, along the coast, of the currents from the Siberian rivers.* As we shall see later, it is more probable that the prevailing surface-current or drift along the Siberian coast has a north-westerly direction.[1]

The occurrence of drifting ice along the coast east of the Taimur Peninsula seems, both according to our experience and that of the Vega Expedition, to be partly determined by the currents from the rivers, the ice having evidently a tendency to occur in the eddies probably formed on both sides of these river currents. Near both the northern and the southern edge of

[1] During their expedition to the New Siberian Islands in the summer of 1886, E. von Toll and A. Bunge observed, according to what *Toll* has told me, that the sea-level was lower during prevailing easterly winds than during periods with much westerly wind, when the level of the water always rose high. This seems to indicate that the current in the sea round the New Siberian Islands generally flows westward, and not eastward.

the current from Khatanga Bay (with low surface salinities), we met with particularly compact ice; while towards the north and south, as well as in the middle of current itself, the ice was more scattered. The Vega met with ice just on the south side of the northern entrance to the bay.

Outside the Anabara, we met with no ice, but there were scattered ice-floes on both sides of the current from this river and it is especially interesting to note that solitary ice-floes (Sept. 15, 1893, noon) occurred in the otherwise open sea midway between the points at which the salinity minima of the Anabara and the Olenek were found. The Vega met with no ice in this locality, but on the other hand she met with ice midway between the minima points of the Olenek and the western branch of the Lena, in about 122° E. Long. The Fram met with ice in the sea to the north of the delta of the Lena, between the longitudes of the mouths of the western and the eastern branches of the Lena. The reason may, however, in this case be that the Fram was here farther north. But the ice came far south in 131° 4′ E. Long., just east of the eastern minimum of surface salinity caused by the Lena. In very much the same longitude (132° E. Long.), but east of the eastern minimum of the Lena, the Vega also met with ice (see Pettersson l. c., p. 362).

We see that the ice at several of these places, *e. g.* between the Anabara and the Olenek, as well as between the Olenek and the western branch of the Lena, occurs in surface-water with comparatively high salinities. Pettersson may be correct in his explanation (l. c., p. 362) that this ice is carried towards the coasts by the under-current of cold, salt water, formed as a reaction-current by the river currents of fresh water on the surface;[1] but I also con-

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[1] Nordenskiöld's observation that a thin film of ice or ice-needles began to appear on the sea-surface outside the delta of the Lena, while the temperature of the surface-stratum was above + 1° C., and the temperature of the air above + 1·5° C., is undoubtedly explained by this underlying cold water, as Pettersson points out (l. c., p. 363). It is evidently the same phenomenon that was often observed by us during the summer in the North Polar Basin, when the sea was covered with a layer of nearly fresh water, which was sharply defined, on its under side, from the cold underlying sea-water, with temperatures of about −1·5° C. The fresh water would then be cooled down so as to form ice upon its under side, and the ice would float up and form a layer of ice-needles, or an ice-crust, on the water-surface, if there were no old ice-floes near, in which case, however, a solid crust of ice would be formed at the under boundary of the fresh water-layer (see later and also Remarks in the Table, pp. 84, *et. seq*).

sider it probable that between two river currents, flowing northward, on the surface, eddies will be formed in which the ice, when once present, will have a tendency to remain.

The fact that the ice occurs so far south all over the Nordenskiöld Sea, between the Taimur Peninsula and the New Siberian Islands, may perhaps be explained in a similar manner.

There appeared to me to be a striking difference in this respect between the to a great extent open sea to the north of the Obi and the Yenisei, and the ice-covered sea east of the Taimur Peninsula, north of the rivers Khatanga, Anabara, and Olenek, and partly the Lena, where we met everywhere, and at no great distance from the coast, with much old, heavy ice. It seems to me that it is possible, that the considerable surface current consisting of the united volumes of water from the Lena and the Yana, flowing northward, west of the New Siberian Islands, forms, in connection with the north-west drift-current of the North Polar Basin, a kind of eddy in the Nordenskiöld Sea, east of the Taimur Peninsula, in which the pack-ice may remain even for years without being carried northward into the North Polar Basin.

This might perhaps also explain the fact why our highest salinities of the sea-surface in connection with the lowest surface-temperatures along the whole Siberian coast, were met with just at the north-east corner of the eastern Taimur Peninsula.

During our northward voyage, from our last minimum of surface salinity north-east of the delta of the Lena in 74° 30′ N. Lat. and 134° E. Long., we sailed through a broad, open sea, where no ice was to be seen, and where the salinity of the sea-surface steadily increased, while the surface temperature remained between about —0·5° C. and —0·8° C. But off Byelkovski Island in 75° 32′ N. Lat. (134° 21′ E. Long.), there was a slight fall in the salinity with a rise in the temperature from 16·71 ‰ (with —0·81° C.) to 14·91 ‰ (with —0·5° C.) which may be due to coast-water from Kotelnoi Island. Towards the north the salinity again increased to 16·77 ‰ (with —0·65° C.).

To the north-west of the Kotelnoi, in 76° 42′ N. Lat. and 136° 14′ E. Long. (Sept. 19, 1893, 8 p. m.) there was a sudden rise in the surface salinity

from 18·08 ‰ (with —0·6° C.) to 22·07 ‰ (with —0·6° C.),[1] which might seem to indicate a surface-current of water with higher salinities coming from the east or south-east, and which we met with as soon as we came sufficiently far north to have the northern extremity of the islands to the east-south-east. Northward from this place, the surface salinity continually increased, while the surface temperature remained between —0·4° C. and —0·6° C., until we approached the edge of the pack-ice in 77° 46′ N. Lat. and 138° 42′ E. Long. (Sept. 20, 1893), near which the surface salinity increased to 27·36 ‰, and the temperature sank to —1·4° C. During the following days in the pack-ice, the surface salinity sometimes increased to above 30 ‰, and the surface temperature sank below —1·5° C.

We see that, upon the whole, the salinity of the sea-surface did not increase so rapidly northward in this sea, as it did along the eastern coast of the Taimur Peninsula, north of Khatanga Bay, where we observed a surface salinity of 30·16 ‰ (with —1·6° C.) in 75° 50′ N. Lat., or more than two degrees farther south. The difference may probably be explained chiefly by the effect of the volumes of the Lena water upon the sea west of the New Siberian Islands.

[1] At this place we also met with a few small pieces of ice (see Table p. 77).

IV.

THE VERTICAL AND HORIZONTAL DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY IN THE NORTH POLAR BASIN.

I designate by the name of the North Polar Basin the deep polar sea, discovered by us to the north of the Asiatic-European Continent, which we tranversed chiefly by drifting in the ice, from September, 1893, to August, 1896. This large basin, with depths of 3850 m., and probably more, is separated from the deep basin of the Norwegian Sea (between Norway, Spitsbergen, Greenland and Iceland) by a ridge or submarine plateau uniting Siberia and Europe with Franz Josef Land and Spitsbergen (see above pp. 281, 288), and by a ridge extending north-west from Spitsbergen, which probably reaches Greenland (see later).

The North Polar Basin has thus the typical character of a large gulf or mediterranean sea, the largest on the Earth, forming the northern termination of the Atlantic Ocean, which, as a long and comparatively narrow arm, extends from the vast Ocean sheet of the World northward between Africa and Europe on the one side, and America on the other. The deep basins of the Atlantic Ocean are separated from the North Polar Basin by several submarine ridges besides the two mentioned above, the most important being the Faeroe-Iceland Ridge, which forms a barrier from Scotland to Greenland.

By its situation as the northern bottom of such a long arm of the Ocean from the deeps of which it is separated by transverse ridges, the physical

conditions of the North Polar Basin are to a very great extent determined, and its oceanographical features are those of a mediterranean sea, which must strike one on the first glance at our curves of deep-sea temperatures and salinities (Pl. X—XIII). Both the temperatures and the salinities of the deep water are higher than those of the adjacent Norwegian Sea.

In order to obtain a general view of the distribution of the temperature and salinity in the North Polar Basin, I have arranged the table given on pp. 306—307. The figures in brackets are the means of the observations taken at the nearest depths above and below, as there were no observations at the desired depth.

This table, taken in connection with the curves of temperature and salinity at the various depths, on Pls. X—XIII, will enable the reader at once to form an idea of the main features of the oceanography of this sea. The uniformity with regard both to temperature and salinity, especially of the deep water of the whole of this sea, is striking, as is also the great and sharply defined difference between the shallow water, above 200 m., and the deep water, deeper than 250 m. In all the series we have a minimum of temperature at from 70 to 80 m., and a maximum at from 300 to 400 m., below which the temperature gradually sinks to a second minimum near the bottom. The salinity, however, increases rapidly from the surface to about 200 or 250 m., where it is about 35·2 ‰, and thus it remains, almost unaltered, to the bottom.

It at once becomes evident that we have here two different kinds of water. The surface of the sea, between 0 m. and 200 m., is covered with water of low salinity and low temperature, the *genuine Polar water;* while the sea from 250 m. to the bottom is filled with water of a very high salinity (35·2 ‰ or 35·3 ‰) and of a relatively high temperature, being above zero Centigrade between 200 or 250 m. and 700 or 900 m. From 400 m. or 500 m. the temperature gradually decreases downward, yet without reaching the low temperature of the upper polar water. The comparatively varm and saline water has evidently its direct origin from the *Gulf Stream* of the Atlantic Ocean.

a. *The Upper Layer of North Polar Water.*

By North Polar Water, I mean the upper layer of the water of the North Polar Basin, which has a temperature below zero Centigrade, and a salinity below 35 ‰. In the sea to the north of the New Siberian Islands (in about 81° N. Lat., 130° E. Long.) this layer is from 215 m. to 250 m. thick, but decreases somewhat in thickness towards the north-west and west, along the route of the Fram. It was thinnest (170 m.) from Stations 19 to 23 (see p. 332). The explanation is evidently that we were there south of the main direction of the whole drift, and nearer to the southern edge of the deep basin.[1] Farther west, at Stations 24—26, the thickness again increased to 195 m. and 190 m. The drift had here taken a step nortward, evidently more towards the centre of the Polar current where the surface layer is thicker.

The salinity of this layer of North Polar Water is, upon the whole, lowest in the eastern part of the Fram's route, and increases slowly towards the west. This is easily seen in the Table on p. 306, especially for depths of less than 100 m. At 40 m., for instance, we found 31·35 ‰ in April, 1894, 32·39 ‰ in June, 1894, 33·23 ‰ in May, 1895, and 33·47 ‰ in July, 1895. The isohalines of Sections, Pls. XIV and XV, therefore rise gently towards the west. But with the increasing salinity, the temperature of the uppermost water-strata — between 0 m. and 100 m. — sinks correspondingly towards the west. This is owing to the fact that the surface water is cooled down to near its freezing-point, and this sinks with the increasing salinity. At 40 m. we found —1·70° C. in April, 1894, but —1·90° C. in May, 1895, and so forth. Thus the minimum of temperature of this polar water also sinks towards the west. In April, 1894, it was —1·76° C. at 60 m.; in June, 1894, —1·76° C. at 60 m.; in October, 1894, —1·78° C. at 50 m.; in May, 1895, —1·90° C. at 50 m.; in July, 1895, —1·88° C. at 50 m.

The surface-layer of nearly fresh snow-water and ice-water formed during the summer. The seasonal changes in the temperature and salinity of the *uppermost water-strata — between 0 m. and 20 m.* — are of special interest. We may assume that the temperature of these strata is generally near the freezing-point of the water, and that consequently the temperature

[1] At Stat. 14 the layer was also comparatively thin, 215 m. This may be because the Station is farther south than Stats. 18, 15, and 16, and nearer to the edge of the basin.

TABLE OF TEMPERATURE (° C.) AND SALINITY (‰).

Depth in m.		1896		1895			1894							1893		Mean
		Stat. 26 April	Stat. 25 Jan. —Feb.	Stat. 24 Nov. —Dec.	Stat. 23 July	Stat. 22 May	Stat. 20 Nov.	Stat. 19 Oct.	Stat. 18 Aug.	Stat. 17 July	Stat. 16 June	Stat. 15 May	Stat. 14 April	Stat. 11 Nov.	Stat. 9 Oct.	
0	° C.	— 1·86	— 1·80	— 1·69	0·16	— 1·70	— 0·24	— 0·16	0·80	0·20	0·34	— 1·71	— 1·55	— 1·43	— 1·6	— 0·87
	‰				31·66	31·37	4·50			1·24	5·05	30·05	30·06	28·40	28·70	21·23
5	° C.	— 1·86	— 1·81	— 1·69	— 1·66	— 1·69	— 1·57	— 1·55	— 1·55	— 1·63	— 1·60		[— 1·56]			— 1·65
	‰						[30·11]	29·90		29·69	29·82		[29·69]			29·84
10	° C.			[— 1·75]	— 1·72	— 1·79	[— 1·56]	[— 1·58]	— 1·55	— 1·62	— 1·62	— 1·65	[— 1·57]	— 1·32		— 1·61
	‰					31·30	30·11	[30·60]		29·56	29·74	30·46	[29·74]	28·33		29·98
20	° C.			[— 1·80]	— 1·79	— 1·77	[— 1·61]	[— 1·63]	— 1·55		— 1·60	— 1·66	— 1·59	— 1·37	— 1·45	— 1·62
	‰				32·31	32·45	[30·16]	[31·20]			29·93	30·32	29·77	28·46	29·35	30·44
40	° C.			[— 1·89]	— 1·88	— 1·90	[— 1·68]	[— 1·73]	— 1·72		— 1·62	— 1·67	— 1·70	— 1·44		— 1·72
	‰				33·47	33·23	[32·30]	[32·95]			32·39	32·42	31·35	31·15		33·41
60	° C.			[— 1·88]	— 1·88	— 1·89	[— 1·74]	[— 1·76]	— 1·72		— 1·76	— 1·73	— 1·76		— 1·45	— 1·76
	‰				33·85	33·90	[33·90]	[33·81]			33·81	33·65	33·40			33·76
80	° C.			[— 1·86]	— 1·86	— 1·87	[— 1·74]	[— 1·70]	— 1·72		— 1·69	— 1·73	— 1·74		— 1·5	— 1·74
	‰				34·18	34·15	[34·16]	[34·06]			34·05	34·11	33·86			34·08
100	° C.			[— 1·83]	— 1·78	— 1·88	— 1·65	[— 1·60]	— 1·62		— 1·58	— 1·60	— 1·61		— 1·62	— 1·68
	‰				34·36	34·26	34·47	[34·30]			34·58	34·42	34·21		32·96	34·20
120	° C.			[— 1·65]	— 1·59	— 1·50	[— 1·24]	[— 1·20]	— 1·47		— 1·32	— 1·43	— 1·50		— 1·38	— 1·43
	‰				34·44		[34·61]	[34·49]			34·47	34·53	34·48		33·73	34·39
140	° C.			[— 1·50]	— 1·48	— 0·84	[— 0·77]	[— 0·75]	— 1·19		— 0·97	— 1·41	— 1·25		— 1·21	— 1·14
	‰				34·47		[34·74]	[34·70]			34·60	34·56	34·70		34·04	34·54
160	° C.			[— 1·13]	— 0·82	— 0·10	[— 0·25]	[— 0·30]	— 0·80		— 0·68	— 1·15	— 0·87			— 0·68
	‰				34·81		[34·90]	[34·90]			34·72	34·59	34·67			34·77
180	° C.	[— 0·23]	[— 0·35]	[— 0·49]	0·12	0·33	[0·17]	[0·10]	— 0·52		— 0·35	— 0·54	— 0·30			— 0·18
	‰				34·83		[35·03]	[35·05]			34·79	34·66	34·63			34·83
200	° C.	0·20	0·15	0·11	0·43	0·78	0·67	0·61	— 0·23		— 0·27	— 0·30	— 0·22			0·18
	‰			34·90	34·98	34·87	35·16	35·20			34·98	34·73	34·76			34·95
250	° C.			0·57	1·04	1·09	0·72	0·74	0·08		0·49	0·00	0·23			0·55
	‰			35·04	35.15	35·11	[35·13]	35·10			35·22	[35·25]	35·07			35·13
300	° C.				1.18	1·04	0·78	0·79	0·22		0·53	0·19	0·27			0·63
	‰				35·16	35·14	35·10	35·19			35·14	35·17	35·09			35·14
350	° C.				1·19	1·08	0·69	0·74	0·28		0·36	[0·28]	0·25			0·61
	‰				35·16	35·22	35·18	35·23			35·22	[35·18]	[35·16]			35·19
400	° C.				0·99	0·87	0·69	0·76	0·32		0·38	0·35	0·36			0·59
	‰				35·14	35·18	35·08	35·32			35·18	35·18	35·22			35·19

450	° C.			0·73	[0·86]	0·74	[0·57]	0·72	0·32		0·40	[0·35]	[0·36]			0·56
	‰			35·15	[35·18]	35·16	[35·11]	35·36			35·26	[35·16]	[35·22]			35·20
500	° C.	0·93	0·83	0·64	0·73	0·64	[0·45]	0·60	0·30		0·30	0·34	0·36			0·56
	‰			[35·15]	35·22	35·14	[35·14]	35·28			35·28	35·14	35·22			35·20
600	° C.	0·64		0·47	0·56	0·58	0·21	0·33	0·16		0·18	0·15	0·15			0·34
	‰			[35·14]	35·20	35·23	35·20	35·12			35·33	35·13	35·25			35·20
700	° C.			0·32	0·47	0·28	[0·10]	0·11	0·10		0·13	0·05	0·07			0·18
	‰			[35·15]	35·20	35·23	35·06	35·24			35·20	35·04	35·30			35·18
800	° C.			0·15	0·12	0·08	[– 0·01]	0·06	0·02		0·01	– 0·04	– 0·03			0·04
	‰			35·15	35·23	35·31	[35·10]	35·26			35·10	35·21	35·35			35·21
900	° C.	0·01	– 0·04	– 0.04	– 0·04	– 0·02	[– 0·12]	[– 0·09]	– 0·09		– 0·06	– 0·08	– 0·03			– 0·05
	‰			35·14	35·07	35·12	[35·15]	[35·25]			35·11	35·29	35·28			35·18
1000	° C.	– 0·21			– 0·33	– 0·23	– 0·23	– 0·25	– 0·14		0·11	– 0·16	– 0·12			– 0·20
	‰				35·39	35·18	35·20	[35·25]			35·11	35·18	35·22			35·22
1200	° C.				– 0·49	– 0·40		[– 0·39]	– 0·32		– 0·34	– 0·32	– 0·32			– 0·37
	‰				35·28	35·24		[35·24]			35·04	35·33	35·24			35·23
1400	° C.				– 0·73			[– 0·54]	– 0·38		– 0·44	– 0·46	– 0·44			– 0·50
	‰				35·24			[35·24]			35·08	35·20	35·28			35·21
1600	° C.				– 0·64			[– 0·67]	– 0·50		– 0·58	– 0·59	– 0·58			– 0·59
	‰				35·23			[35·26]			35·11	35·20	35·21			35·20
1800	° C.							[– 0·76]	– 0·65			– 0·69	– 0·67			– 0·69
	‰							[35·29]				35·19	35·24			35·24
2000	° C.							– 0.86	– 0·71			– 0·76	– 0·75			– 0·77
	‰							[35·31]				35·16	35·23			35·23
2200	° C.							[– 0·87]	– 0·74			– 0·80	– 0·79			– 0·80
	‰							[35·34]				35·29	35·16			35·26
2400	° C.							[– 0·88]	– 0·77				– 0·82			– 0·83
	‰							[35·37]					35·33			35·35
2600	° C.							[– 0·88]	– 0·79							– 0·83
	‰							[35·36]								[35·36]
2800	° C.							[– 0·86]	– 0·80							– 0·83
	‰							[35·31]								[35·31]
3000	° C.	– 0·87						– 0·84	– 0·78							– 0·83
	‰							35·27								35·27
3200	° C.								– 0·76							– 0·76
	‰															
3400	° C.								– 0·74							– 0·74
	‰															
3600	° C.								– 0·71							– 0·71
	‰															
3800	° C.								– 0·69							– 0·69
	‰															

changes with the salinity. During the summer, especially during the month of July, the snow on the ice, and the upper layers of the ice itself, are melted by exposure to the sun, and the sea-water in the channels and lanes between the ice-floes is covered by a layer of nearly fresh ice-water and snow-water, with a temperature of about, or even above, 0° C. This layer, on July 11th, 1894, had a thickness of about 2 m. with salinities between 1·20 ‰ and 2·22 ‰ (see Table, p. 249). Capt. Scott-Hansen made numerous observations of the temperature and thickness of this layer during the several years of the expedition (see Table, pp. 82 *et seq.*). In the summer of 1894, the layer began to be formed in the water-hole near the Fram after June 5th, when the surface-temperature was still —1·58° C., while on June 9th it had risen to 0·15° C. even at 0·3 m. On June 26th, 1894, the temperature at 0·2 m. was 0·34° C. and the salinity 5·06 ‰ (see p. 248). During July the layer increased greatly in thickness; but it was naturally not so thick in open water-lanes as it was in narrower and more enclosed channels between the floes, or in the water-hole where the observations were generally made (cf. Scott-Hansen's various series of observations).

As may be seen from the series of observations taken on July 11th, 1894, the salinity of this layer of water is very low, between 1 and 2 ‰, and varies very little. Scott-Hansen's various series taken in July and August, 1894, also demonstrate that the temperature of the layer is relatively uniform; it remains above 0° C. down to a certain depth, where it suddenly, generally in less than 0·3 m., falls from 0° C. to —1·35° C. (cf. series July 9th to August 24th, 1894). This layer of nearly fresh water thus rests, with a very sharply defined boundary, upon very cold water; and while it is heated by the sun from above, so that its temperature sometimes even rises above + 1° C. (cf. August 6th and 11th, 1894), it is constantly cooled down from below near its lower boundary, and at this depth ice is generally being formed. Along the edges of the ice-floes, a distinct, projecting crust or collar of ice may therefore often be observed at this depth, from which long, slender ice-needles project horizontally into the water.[1] If the distance between the ice-floes on the two sides of a channel be not considerable, an ice-crust may be formed between them upon the under side of the fresh-water layer, as was

[1] I observed similar conditions in Denmark Strait, near the east coast of Greenland, in July, 1882.

often observed by us in 1894, in the water-holes and narrow channels near the ship. On July 11th, 1894, we found an ice-crust at 2·3 m. (soft, 3 cm. thick, see p. 121), on July 17th, at 2 m. (p. 84), on July 30th, at 1·6 m., on August 3rd, 1894, at 1·6 m. (a soft ice-crust 2 cm. thick, see p. 87). On September 7th, 1894, a layer of solid ice, 3 cm. thick, and porous on the lower surface, was found at 1·2 m. (see p. 90, and foot-note, p. 91), on September 10th, at 0·75 m., on September 14th, at 1·15 m. (12 cm. thick), on September 17th, at 1 m. (8 cm. thick), on September 21st, at 1 m., on September 24th, at 1 m. (15 cm. thick), on October 1st, 1894, at 1 m.[1] This layer of ice was sometimes quite thin and porous, but sometimes thick and so strong, that it was difficult to make a hole through it with a wooden rod.

Under ordinary circumstances, ice is naturally always formed at the boundary between this fresh-water layer and the underlying cold sea-water; but if the margins of the ice-floes on the two sides of a channel, are too far apart to act as an attachment for the net of ice-needles first formed, these needles cannot unite to form an ice-crust *in situ* under the water, but must rise, and if they are not melted again, will form a crust on the surface. We may thus see an ice-crust formed on the surface of water with a temperature above 0° C., even approaching 1° C. (cf. August 11th and 20th, 1894, p. 88). As already mentioned (p. 300), it was evidently this phenomenon that was observed by Nordenskiöld on the sea-surface outside the delta of the Lena, where the river-water probably formed a similar layer resting on cold polar water.

The fresh-water layer formed during the summer of 1894 remained for a long time during the following autumn and winter, in spite of the continued low temperature of the air[2], as may be seen from the following table, in which I have placed together Scott-Hansen's observations of the temperature of the water between 0 m. and 3 m. in the same water-hole near the Fram,

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[1] The reason why the ice-crust was found at the greatest depth on July 11th and 17th, was evidently that the water-hole was then more enclosed, so that the water produced by the melting could accumulate in it more abundantly. Subsequently cracks and channels were formed in the ice, so that the water-hole communicated with larger lanes, and the fresh-water layer was more spread.

[2] The mean temperature of the atmosphere was approximately, in

August, 1894,	−1·0 ° C.,	November, 1894,	−30·8 ° C.,
September, „	−8·27° C.,	December, „	−34·95° C.,
October, „	−22·55° C.		

from September 7th to December 18th, 1894, (cf. Table, pp. 90—92). The temperature-readings taken on very cold days are probably somewhat too low, owing to the lowness of the temperature of the air (cf. p. 240), this being given in the third line from above of the table. I have therefore reduced the temperature in the proper proportion on such days. Below each

	Sept. 7th.	Sept. 10th.	Sept. 14th.	Sept. 17th.	Sept. 21st.	Sept. 24th.	Oct. 1st.	Nov. 3rd.	Nov. 12th.	Nov. 19th.	Nov. 30th.	Dec. 4th.	Dec. 11th.	Dec. 18th.
Air.	−6·0	−4·5	−2·5	−7·6	−14·2	−14·2	−14·9	−34	−35·4	−15·6	−35·4	−34·2	−33·6	−42·2
0 m.	−0·09 [1·8]	−0·09 [1·8]	−0·10 [2·0]	−0·09 [1·8]	−0·09 [1·8]	−0·11 [2·1]	−0·11 [2·1]	− 0·2 [4·0]	−0·35 [6·6]	−0·48 [8·9]	−0·67 [12·2]	−0·82 [14·8]	−1·37 [24·5]	−1·77 [31·6]
0·5 „			−0·16 [3·2]	−0·16 [3·2]		−0·11 [2·1]		−0·2 [4·0]						
1 „	−0·16 [3·2]	−0·16 [3·2]	−0·16 [3·2]	−0·16 [3·2]	−0·16 [3·2]	−0·16 [3·2]	−0·16 [3·2]	−0·3 [5·7]		−0·52 [9·6]	−0·77 [14·0]	−0·9 [16·2]	−1·4 [25·0]	
1·25 „	−1·36 [24·4]													
1·5 „	−1·56 [27·9]	−1·31 [23·5]	−1·53 [27·3]	−1·56 [27·9]	−1·49	−1·56 [27·9]	−1·56 [27·9]			−0·77 [14·0]	−1·47 [26·3]	−1·5 [26·8]	−1·7 [30·3]	−1·8 [32·1]
1·75 „										−1·62 [28·9]				
2 „	−1·56 [27·9]	−1·54 [27·5]	−1·53 [27·3]	−1·56 [27·9]		−1·56 [27·9]	−1·56 [27·9]	−1·6 [28·6]		−1·67 [29·8]	−1·67 [29·8]	−1·7 [30·3]	−1·7 [30·3]	
2·5 „		−1·56 [27·9]		−1·56 [27·9]										
3 „	−1·56 [27·9]	−1·56 [27·9]	−1·56 [27·9]	−1·56 [27·9]	−1·56 [27·9]	−1·56 [27·9]	−1·56 [27·9]	−1·6 [28·6]	−1·72 [30·7]	−1·67 [29·8]	−1·67 [29·8]	−1·7 [30·3]	−1·7 [30·3]	−1·8 [32·1]

water-temperature I have added, in brackets, the salinity of water which would have a freezing-point similar to the observed temperature. These figures probably represent very nearly the salinities of the water, as ice was at that time continually being formed, and we may assume that the water was cooled down almost to its freezing-point. We see that the fresh-water layer remains very nearly unaltered during the whole month of September, and even October. During November the temperature of the layer gradually sank, and the salinity was evidently increased accordingly by the freezing process, until there was a sudden change in December, and the whole layer disappeared in a short time. On December 4th, 1894, the

layer was still quite distinct; on December 11th, we see there were traces of it at 0 m. and 1 m., but on December 18th it had disappeared, and the temperature of the sea-surface had sunk to —1·77° C.; and it remained very nearly at this temperature during the whole winter.

During the first autumn (1893) of the Fram's drift, there was no indication of a surface-layer such as this of water with a very low salinity. The surface-salinity remained, as a rule, between 27 and 31 ‰ during that autumn and the following winter, as may be seen from the Table, pp. 161 to 163. It is lowest, upon the whole, in October and the beginning of November, when we were far south.[1] The temperature at the sea-surface during that period seems to have been continually very near the freezing-point of the sea-water. It might appear as if, even in September, 1893, it had often been below this, but this has probably not been the case; the determination of the temperature, especially during the autumn of 1893, may have been somewhat inaccurate, and was perhaps influenced by the low temperature of the air. As a rule, the temperature was only read off with an accuracy of 0·1° C. (see Table, pp. 78 to 82). After December, 1893, the determinations have evidently been made with more accuracy, and a better thermometer, Müller No. 7, was also generally used for the determinations from January to April, 1894. In the following table, giving the salinities and temperature of the sea-surface from December 1st, 1893, to April 16th, 1894, I have also added the freezing-points which sea-water with these salinities would have according to Pettersson's investigations.[2] We see that if Pettersson's determinations of the freezing-point of sea-water with various salinities are fairly accurate, the determinations of the surface-temperature made in December, 1893, are still almost continually more or less below the freezing-point of the surface-water; while after January 23rd, 1894, the values obtained are as near the freezing-point as can be expected from determinations which are made with no higher a degree of accuracy than these. It is evident that the determinations made of the surface-temperature in December, 1893, and the previous months, are less correct.

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[1] There are great variations in the surface-salinities given in the table, but this may to a very great extent be due to various incidental circumstances, *e. g.* whether the water-samples were taken in different channels or water-holes, whether there had just been much wind, covering the water-surface with drifting snow, etc.

[2] Pettersson, "On the Properties of Water and Ice", Vega Exp. Vet. Iaktt., vol. II, p. 270.

Temperature and Salinity of the Sea-surface, with the Freezing-Point.

Date.	Salinity.	Temperature.	Freezing-Point.	Date.	Salinity.	Temperature.	Freezing-Point.
1893.	‰	° C.	° C.	1894.	‰	° C.	° C.
Dec. 1	28·69	—1·72	—1·61	Feb. 5	28·92	—1·6	—1·62
„ 3	28·64	—1·62	—1·60	„ 14	29·37	—1·6	—1·64
„ 5	29·70	—1·67	—1·67	„ 16	28·89	—1·6	—1·62
„ 6	27·83	—1·62	—1·56	„ 19	28·56	—1·6	—1·60
„ 7	27·93	—1·62	—1·56	„ 21	28·92	—1·65	—1·62
„ 8	27·70	—1·62	—1·55	„ 28	30·24	—1·65	—1·69
„ 20	27·55	—1·72	—1·54	March 5	29·36	—1·65	—1·66
„ 21	27·66	—1·49	—1·55	„ 12	29·88	—1·6	—1·68
1894.				„ 15	29·22	—1·61	—1·64
				„ 19	28·80	—1·6	—1·61
Jan. 23	29·13	—1·62	—1·63	„ 24	29·65	—1·61	—1·66
„ 28	28·42	—1·57	—1·59	„ 30	29·48	—1·61	—1·65
„ 29	28·63	—1·55	—1·60	April 3	29·79	—1·63	—1·67
Feb. 1	28·82	—1·57	—1·61	„ 10	29·66	—1·63	—1·66
„ 3	29·16	—1·6	—1·63	„ 16	29·49	—1·61	—1·65

During the summer of 1895, the layer of melted ice-water in the channels and lanes near the Fram, seems to have been much thinner and with lower temperatures than in the previous year (cf. Table, pp. 94 and 95). On July 20th and 27th, 1895, it seems to have reached a thickness of about 1 m. and only on July 13th, 1895, does the temperature at the surface seem to have been remarkably high — as much as 2·63° C., at 0·1 m., and 1·33° C. at 0·15 m., while it was —0·27° C. even at 0·25 m., and —1·69° C. at 0·5 m. This seems, however, to have been an exceptional case. On July 20th and 31st, 1895 (p. 254), the temperature at or near the surface was also above 0° C. but all observations taken on other dates show temperatures below 0° C., even at the surface, and in August, 1895, they are even below —1° C. There is unfortunately only one determination of the salinity at the surface from this period, *viz.* 31·66 ‰ on July 31st, 1895 (see p. 189); but this is evidently not the salinity of the water at 0 m., the water-bottle having probably been closed at 1 or 2 m. The reason why the surface-layer of melted ice-water was so much less observable in the summer of 1895 than in the previous summer may to a very great extent have been that the observations were evidently not taken in a water-hole, but in open lanes. There was, upon the whole, much movement in the ice round the Fram during the summer

of 1895[1]; broad lanes were incessantly formed, and on August 9th, 1895, the Fram was even released for a short time from the ice-floe into which she had been frozen. The surface-layer of melted snow and ice was thus never allowed sufficient time to develope undisturbed in narrow channels and water-holes as in the previous year, but was stirred up and mixed with the underlying water in the broader lanes.

On the other hand, there had evidently also been less melting of snow and ice during the summer of 1895 than during the previous summer, for the approximate mean temperature of the air during the summer months was

	June	July	August
1894	−1·52°C.	0·25°C.	−1·0 °C.
1895	−2·2 -	−0·27 -	−2·56 -
1896	−1·74 -	−0·09 -	1·10 -

During the summer of 1896, only a few series of temperatures were taken below the sea-surface (on July 14th and 29th). These prove, however, that the surface-layer of melted snow and ice was of insignificant depth, evidently because the Fram, during July and August, 1896, was working her way southward, and the openings in the ice round her were as a rule comparatively large, so that the fresh water formed by the metting of the snow and ice was much mixed with the underlying water. The often relatively high surface-temperatures (*e. g.* July 31st, August 2nd, etc.) seem, however, to indicate that a surface-layer such as this was sometimes, at any rate, actually present.

The seasonal changes in temperature and salinity near the surface. The surface-layer of nearly fresh, and comparatively warm, water, formed during the summer has naturally some effect upon the temperature and salinity of the immediately underlying sea-water. But, as we have already seen, this effect is not very great, nor does it reach to any great distance below the surface, as may be gathered from Scott-Hansen's series of temperatures given on pp. 82 *et seq.* and from our series of temperatures and salinities given in the tables on pp. 246 *et seq.* and pp. 306—307.

[1] Cf. Sverdrup's description in 'Fram over Polhavet', vol. II, pp. 425 *et seq.*

According to these tables, we find the following temperatures in degrees Centigrade at depths from 3 m. to 20 m.:

m.	1894								1895			1896		
	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	May	July	Aug.	May	June	July
3		−1·5	−1·49	−1·46	−1·56	−1·56	−1·64[1]	−1·7[1]	−1·69[1]	−1·68	−1·65			
5		−1·60	−1·63	−1·55		−1·55					−1·70	−1·90	−1·82	−1·8
10	−1·65	−1·62	−1·62	−1·55			−1·56		−1·79				−1·80	−1·8
20	−1·66	−1·60		−1·55			[−1·61]		−1·77	−1·79				
30	−1·62	−1·60		−1·60			[−1·65]		−1·80					
40	−1·67	−1·62		−1·72		[−1·73]	[−1·68]		−1·90	−1·88				

We see that the changes in temperature are very small even at 3 m., where the maximum is in August, but seem to be nearly equally great at 20 m. At 30 m. there may perhaps also be a slight indication of a seasonal change in the temperature; but at 40 m. this is more doubtful, as the variations in the observed temperatures at this depth (see Table, p. 306) do not seem to be due to regular seasonal changes.

In the salinity of the water-strata there are similar seasonal changes (see Table, p. 306). At 10 m. the diminution of the salinity during June and July, 1894, is very distinct. At 20 m. there is still perhaps a slight indication of these changes, that of June, 1894, being smaller than that of May; but the increase of the salinity towards the north-west is more predominant at this depth (see Section Pl. XV.). We thus find the lowest salinity at 20 m. (28·46 ‰), at the most easterly station in November, 1893 (Stat. 11), a higher salinity (29·35 ‰) towards the north-west in October, 1893 (Stat. 9), and one still higher farther to the north-west in April (29·77 ‰) and May (30·32 ‰), 1894 (Stat. 14 and 15). In June, 1894 (Stat. 16), there was, however, a slight fall to 29·93 ‰, but farther towards the north-west, the salinity at 20 m. increased greatly, being 32·39 ‰ in May, 1895 (Stat. 22). In July, 1895 (Stat. 23), there was again a slight fall to 32·31 ‰.

At 40 m. there is no distinct indication of a seasonal change in the salinity. There is a slight decrease in June, 1894, from 32·42 ‰ (in May, 1894)

[1] The temperatures taken with the glass bottle and an inserted thermometer are certainly too low at such cold periods (see above, *e. g.* pp. 91, 92, and also 239); but it is difficult to determine the correction that ought to be applied.

to 32·39 ‰; but this is insignificant, and on all other dates there is a steady increase of the salinity at 40 m. towards the north-west along the Fram's route, from November, 1893, to July, 1895, and no decrease is traceable in the summer of 1895.

At 60 m. there are certainly no seasonal changes to be discovered in our salinities, which, at this depth, increase continuously towards the north-west along the Fram's route.

We thus see that the water formed on the surface of the North Polar Basin by the melting of the snow and ice during the arctic summer, may have an influence upon the underlying water down to 40 m.; but this effect is not traceable at 60 m. On the other hand, we have seen above that, upon the whole, the temperature of the water-strata between 0 and 100 m. sinks continuously towards the north-west, while the salinities increase in the same direction.

As it is probable that the evaporation from the surface of the cold, and generally ice-covered, North Polar Basin is less than the precipitation, it might have been expected that the salinity of the water near the surface would to some extent decrease during its drift across this sea. This, however, is not the case, as we see if we consider not only the immediate result of the melting during the summer, but the result for the whole year.

What then is the origin of the layer of north polar water, about 200 m. thick, covering the North Polar Basin?

I think there can be little doubt that this layer, in the sea traversed by the Fram, is chiefly formed by the admixture with the sea-water of the volumes of fresh water from the Siberian rivers. It is therefore quite natural that we should find the salinities of this layer lowest to be in the first part of the Fram's drift, when we were nearest to the Siberian coast. The salinities observed by us were particularly low during the first autumn, in October and November, 1893, when we were in the shallow sea to the north of the New Siberian Islands. During the drift of this water towards the north-west, the salinity gradually increases, chiefly by mixture with the sea-water of the underlying strata, and the water from the surface in adjacent parts of the sea (see later), but also to some extent by the continual formation and growth of the ice on the surface.

The *influence of the formation of ice upon the salinity* near the surface may be traced in some of our observations. It is a general feature that

especially during the winter, the salinity near the surface is higher than at 10 m. or even at 20 m. In April, 1894, when the temperature of the atmosphere was about —18°C. and the ice was growing continually, we observed

Depth	Salinity	Temperature		Freezing Point
		Origin. Value	Final Value	
0·5 m.	30·06 ‰	—1·62°C.	—1·55°C.	—1·69°C.
1 -	29·67 -			—1·66 -
20 -	29·77 -	—1·66 -	—1·59 -	—1·67 -
40 -	31·35 -	—1·77 -	—1·70 -	—1·75 -

We see that the salinity, even at 20 m., was considerably lower than at 0·5 m. It is a noteworthy circumstance that the deeper water with the lower salinity has also a somewhat lower temperature (in this case 0·04°C. lower) the observation of this being often repeated (*e. g.* in May and June, 1894 May, 1895). Can the explanation be that in this case the water at 20 m. is very slightly cooled from below, where the water is colder, while heat is set free by the freezing near the surface of the narrow water-hole? According to our Table of the final values (p. 246), the temperature at 0·5 m. should have been —1·55°C., and at 20 m. —1·59°C. on April 14th, 1894, while the freezing-point of the water of 30·06 ‰ is about —1·69°C.[1], and of 29·77 ‰ about —1·67°C. It thus seems as if the temperature both at 0·5 m. and at 20 m. was not near the freezing-point of the water. Our final values of the temperature are, however, obtained by a correction according to Table 1 on p. 240, and it is possible that the temperature-readings have not been so much influenced by the low temperature of the air in this case; but even the values we originally obtained, viz. —1·62°C. at 0·5 m. and —1·66°C. at 20 m., given on p. 111, are a little above the freezing-point.

On May 22nd, 1894, when the temperature of the air was between —5·4°C. and —8·4°C., and the ice was still growing, we found

[1] See O. Pettersson, 'Vega Expeditionens vetensk. Iakttagelser', vol. II, p. 270.

Depth	Salinity	Temperature		Freezing Point
		Origin. Value	Final Value	
0·3 m.	30·05 ‰	−1·71°C.	−1·71°C.	−1·68°C.
10 -	30·46 -	−1·67 -	−1·65 -	−1·71 -
20 -	30·32 -	−1·68 -	−1·66 -	−1·70 -
40 -	32·42 -	−1·69 -	−1·67 -	−1·81 -

We see that the value obtained of the temperature at the sea-surface is even somewhat below the freezing-point of the water, but the value −1·68°C. obtained with the thermometer Müller No. 7 and the Negretti and Zambra reversing thermometer, is probably more correct than that obtained with the thermometer Grave (−1·76°C.). The temperatures at 10 and 20 m. seem also to have been very near the freezing-point. On the above date the salinity was also somewhat lower, with a slightly lower temperature, at 20 m. than at 10 m.

On June 22nd and 26th, 1894, we found

Depth	Salinity	Tempera-ture	Freezing Point
5 m.	29·82 ‰	−1·60°C.	−1·67°C.
10 -	29·74 -	−1·62 -	−1·67 -
20 -	29·93 -	−1·60 -	−1·68 -
30 -	30·16 -	−1·60 -	−1·69 -

The ice, at this time, was melting on the surface, and a surface-layer of nearly fresh water was formed; but under this layer, at depths of from 5 to 30 m., we see that the temperature of the water was fairly near the freezing-point, and the salinity of the water was somewhat higher at 5 m. than at 10 m. There is a possibility that new ice was still being formed on the under surface of the ice-floes, as the temperature of the interior of the ice was still below freezing-point; and in this manner an explanation may be found of the fact that the salinity was higher at 5 m. than at 10 m., but it is perhaps more

probable that the higher salinity at 5 m. may be due to the brine always contained in the porous ice. This brine is probably continually being mixed with the upper water-strata by a slow diffusion. The salinity of this brine is much decreased with the rising temperature of the ice in the spring and summer, but at the same time its quantity, as well as the porosity of the ice, is correspondingly increased. Even on July 11th, 1894, we found the salinity higher at 5 m. than at 10 m., and the temperature of the water both at 5 and 10 m. near its freezing-point.

Depth	Salinity	Temperature	Freezing Point
3 m.	29·16 ‰	−1·59°C.	−1·63°C.
5 -	29·69 -	−1·63 -	−1·66 -
10 -	29·56 -	−1·62 -	−1·66 -

The temperature of the air at this time was generally above zero Centigrade (July 11th, +1°C.), and the ice was melting rapidly on the upper surface; but it is hardly probable that it melted on its lower surface.

In August the salinities were not determined, but on August 13th, I observed the same temperature, −1·55°C. at 5, 10, and 20 m. Thus it is probable that the conditions were similar to those of July and June.

On November 3rd, 1894, when the temperature of the air was −34°C., we found

Depth	Salinity	Temperature		Freezing Point
		Origin. Value	Final Value	
2 m.	30·12 ‰	−1·71°C.	−1·56°C.	−1·69°C.
10 -	30·11 -	−1·71 -	−1·56 -	−1·69 -
25 -	30·22 -	−1·77 -	−1·63 -	−1·69 -

There was even a slight indication at this time of a higher salinity at 2 m. than at 10 m., but the temperature of the water at 2 and 10 m. is not very near the freezing-point, if we take the final values, which seem to be the most correct. This is, however, easily explained, as the water-surface was

still covered with a layer of nearly fresh water (4·5 ‰) formed during the summer, with temperatures of about —0·20°C., and this water-layer had naturally a heating effect upon the underlying water.

On April 6th, May 13th, 24th, and 25th, 1895, Blessing made the following observations:

Date	Depth	Salinity	Temperature		Freezing-Point	Temperature of the Air
			Origin. Value	Final Value		
1895						
April 6	0 m.	31·00 ‰	—1·91°C.	—1·78°C.	—1·74°C.	—32·0°C.
	5 -	31·15 -	—1·86 -	—1·73 -	—1·75 -	
May 13	0 -	31·37 -	—1·70 -	—1·70 -	—1·76 -	—10·4 -
	10 -	31·30 -	—1·82 -	—1·79 -	—1·75 -	
	20 -		—1·80 -	—1·77 -		
	30 -		—1·83 -	—1·80 -		
May 25	0 -	32·05 -	—1·73 -	—1·73 -	—1·79 -	—7·9 -
	20 -	32·45 -			—1·81 -	

Only on May 13th is there a slight indication of a higher salinity at 0 m. than at 10 m. The temperatures of the water seem upon the whole to have been very near the freezing-point on these dates, or in some cases even below it, especially on April 6th; but this is probably due to the inaccuracy of the determination, caused by the low temperature of the air.

At the Vega's winter-harbour at Pitlekai, observations of the temperature and salinity of the water-strata between 0 m. and 10 m. were made during the winter of 1878—1879. According to these observations (see Pettersson, l. c., p. 373), we also see that the water-strata near the surface have often had a higher salinity than the underlying water (*e. g.* March 11 at 8 m., April 14 at 2 m., May 3 at 4 m.). The salinities observed near the sea-surface are very similar to ours — about 29 ‰ and 30 ‰ —, but the temperature-readings are very much lower than ours, and as Pettersson points out, often much below the normal freezing-point of the water. Temperature-readings even as low as —3·0°C. were taken. These observations are evidently,

in my opinion, erroneous, for if such abnormal conditions could occur during one winter at Pitlekaj, it seems improbable that we should never have made similar observations during our three years in the North Polar Basin. There may either have been some defect in the thermometer, which may also have caused the low temperature-readings taken in the water-samples from the depths of the Kara Sea (see above, p. 280)[1], or the readings may, in the above case, have been lowered by the low temperature of the air, which seems probable, as the temperature-readings taken in May, and still more in June, are not as low as those taken in March and April, while there is no appreciable reduction in the specific gravity or salinity of the water. The very low temperatures observed in the sea by previous expeditions, some of which are mentioned by Pettersson (l. c., p. 374), are evidently all of them more or less erroneous.

In the series of temperatures and salinities taken during the voyage of the Vega along the Siberian coast, there are also sometimes slight indications of the salinities being higher near the surface than at a depth of 4 or 5 m., *e. g.* on September 11th, 8 p. m., Sept. 14th, 8 a. m., Sept. 20th, noon, 1878 (Pettersson, l. c., pp. 369, 370); and in many series we find that the salinity has a decided tendency to remain almost unchanged in the uppermost water-strata, down to 10 or 20 m., while deeper than 20 m. it increases rapidly with the depth[2].

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[1] Such errors may, for instance, easily occur if some mercury has evaporated and been condensed in the upper bulb or reservoir of the stem of the thermometer, and the observer takes his temperature-readings without examining the upper reservoir with a lens.

[2] Mr. *Martin Knudsen* found in the polar current near Iceland, that the water near the surface — at 20 to 30 fathoms (38 to 57 m.) — very often, or even as a rule, had a higher salinity and density than the immediately underlying water (see 'The Danish Ingolf Expedition', vol. I, No. 2, Hydrography, 1899, p. 136, and Tables, pp. 76 *et seq.*). Knudsen believes that this water, which generally has a low temperature, originates from the brine formed in the ice during freezing. He supposes this brine to accumulate in cavities in the ice formed during the ice-pressures, and being carried along with the ice, it gets "its place underneath the stratum of water that is formed when the ice is melting, while underneath, another layer will be found, originating from former melting of ice". This explanation is at any rate incorrect in some points. It seems, however, to be very doubtful whether Knudsen's observation of a higher salinity at from 20 to 30 fathoms is not merely accidental. During our many series of very accurate observations made on board the 'Michael Sars' in July and August, 1900, in the polar current near Iceland, I did not find in a single case that the salinity of the cold polar water did not increase with the depth from the surface downward, although many of our stations were quite similar to Knudsen's.

The formation of ice on the sea-surface. The question has been discussed by several authors[1] whether the ice of the polar sea is actually formed on the surface of the sea, and whether the whole body of water must be cooled down to its freezing-point before ice can be formed on the surface, as the temperature of the maximum density of sea-water with a salinity above 24 ‰, is below its freezing-point. Our investigations in the North Polar Basin prove that the ice, under ordinary circumstances, is there formed on the surface, and that underlying water is not, as a rule, quite cooled down to its freezing-point. The formation of ice is there greatly facilitated by the vertical distribution of the salinity in the upper water-strata, which makes the density of the water increase very rapidly downward, so that the water cooled down by the emission of heat from the surface, or by the contact with the cold ice, cannot sink much, as it is generally resting on still heavier water, and may thus freeze *in situ*. We have also seen, however, that during the winter the salinity of the uppermost water-strata is so much increased by the continuous formation of ice, that it is very often higher than that of the immediately underlying strata, even during the summer (at 5 and 10 m.); and it seems to take some time before it sinks down to its natural equilibrium. We may thus infer that even in this case the formation of ice will take place at the surface of the water, at the contact with the overlying ice, and not at some depth below; for the water will evidently not be able to sink sufficiently rapidly to keep pace with the cooling at its surface of contact with the overlying ice, and the result must be a continuous growth of the latter.

Only in special cases, when, during the summer, the sea was covered with a layer of nearly fresh water, resting on water with temperatures below —1°C., have we observed the continuous formation of ice at the boundary between the freshwater and the underlying sea-water.

From what has been stated above, it appears that the freezing process has a tendency to give the water near the surface of the North Polar Basin a somewhat higher salinity and density than the immediately underlying water, even in the summer; and the difference thus produced in the salinity and

[1] Cf. M. Knudsen, l. c., p. 138.

density is not at once eliminated by the sinking of the heavier water, this sinking being evidently very slow. But on the other hand, it is evident that when a certain point is reached, the salinities and densities of the uppermost water-strata must be continuously so much increased above those of the underlying water, by the continuous formation of ice, that vertical currents are formed. Our series of observations prove, however, that the heavier surface-water cannot sink very deep, before it meets with water of equal density, this perhaps being at a depth of 20 or 25 m. at the end of the winter. During the summer, the salinity of the uppermost water-layers, perhaps down to 30 or 40 m., is somewhat diminished by the melting of the snow and ice on the surface; but during the following winter the salinities of these water-strata are again still further increased by the formation of new ice, and we must expect the quantity of ice formed during the year to be greater than the contribution of fresh water which the sea-surface receives from the precipitation.

The final result of this process must be that the salinities of the uppermost water-strata of the North Polar Basin are, upon the whole, increased from one year to another during their drift from the Siberian coast towards the sea between Spitsbergen and Greenland; and this is what we observed along the route of the Fram. But at the same time our observations prove that the salinity of the water below a depth of 25 or 30 m. cannot be increased by the formation of the ice on the surface of the sea traversed by the Fram. We nevertheless found that the salinity of all water-strata down to at least 100 m., continually increased towards the north-west along the Fram's route. This can hardly be due simply to the diffusion of the underlying water, as this diffusion is probably too slow. Nor can it be owing simply to a mechanical mixture with the underlying water (Gulf Stream water) with a higher salinity; for this water also has a higher temperature, and a mixture such as this would then lead to an increase of the temperature also, and we found, on the contrary, that the temperature of all water-strata higher than 100 m. sank, upon the whole continuously, towards the north-west.

I believe that we must seek another explanation. We may, however, first discuss

The origin of the water with a minimum of temperature at from 50 to 60 m. We have mentioned above that in all our series of observations in

the North Polar Basin, we find a minimum of temperature at about 50 or 60 m. The following table gives the depths of these minima and the salinities of the water at the same depth:

	Depth.	Minimum-Temp.	Salinity. ‰	Freezing Point.
October, 1893	100 m.	—1·62° C.	32·96	—1·84
April, 1894	60 „	—1·76 „	33·40	—1·87
May, —	60 „	—1·73 „	33·65	—1·88
June, —	60 „	—1·76 „	33·81	—1·89
August, —	50 „	—1·75 „		
November, —	50 „ ?	—1·77 „ ?	33·81	—1·89
May, 1895	50 „	—1·90 „	33·60 ?	—1·88
July, —	60 „	—1·88 „	33·85	—1·89

We see that the water with these minima of temperature cannot possibly originate from the surface of that part of the sea where the temperature-readings were taken, as we there found no water with such a salinity and such a low temperature near the surface. According to what has been stated above, it seems also evident that it cannot originate from brine formed in the ice while freezing, as this brine would have to sink down through the overlaying water-strata with a higher temperature and lower salinity. It seems clear to me that this colder water must originate from other parts of the North Polar Basin, where the water near the surface has a similar salinity. This is probably the case in the sea to the north of the Fram's route, for the salinity of the surface evidently increases towards the north, with the distance from the Siberian coast. We have also seen above that the surface-water of the Kara Sea and the Barents Sea, as well as the sea to the north of Novaya Zemlya, may have a much higher salinity (with low temperatures) than that of the North Polar Basin. In places where the water near the surface has a salinity of about 34 ‰, for instance, the temperature of the water will sink to the freezing point, —1·90° C., during the winter, and the density of the water will be about 1·0273, while the density of the water between 0 m. and 50 m. along the Fram's route, generally varied between 1·0240 and 1·0270. The consequence of this must be that the lighter

water will have a strong tendency to spread horizontally over the heavier surface-water to the north (and also to the south-west in the sea north of Novaya Zemlya), while the surface-water in these regions will flow horizontally in the opposite direction under the lighter water, and will help to form the water-stratum with a minimum of temperature observed by us at 50 and 60 m. As this cold water is probably heated a little on its way by the overlying and underlying warmer water, we may expect its temperature to be a little above the freezing-point. From the above table it appears that this is generally the case. The circumstance of the temperatures from May and July, 1895, being at, or even below, freezing point is probably due to less accuracy of the determinations, as these temperatures were taken with the Negretti and Zambra reversing thermometers, the instrumental correction of which may at that time have been a little less than was assumed.

The final result of this process must be that the salinity of the north polar water, down to some distance below the above mentioned minimum of temperature, say down to 80 m., is constantly increasing, while the temperature falls, during each polar winter, as we found it did along the Fram's route. But the effect of the freezing process on the surface does not seem to extend to depths greater than 100 m., and the consequence is that below this depth we did not find the temperature of the water-strata sinking towards the north-west along our route. At 120 m. and 140 m., both temperature and salinity seem to remain more or less the same, except from October, 1893, to April, 1894, when there was a distinct increase of the salinity. At 160 m., and still more at 180 m., there is, upon the whole, a distinct rise in the temperature towards the north-west, while the salinity exhibits no great changes. At 200 m. the rise in temperature towards the north-west is still more distinct, and a tendency towards increasing salinities in the same direction may also be traced.

This rise in the temperature, and partly also in the salinity, at these depths between 160 and 200 m., is evidently due to the underlying warmer Gulf Stream water; the cold water may partly be heated from below, and partly also be mixed by diffusion and friction with the underlying warm water, probably flowing in an opposite direction.

By taking the salinity at every 20 m. between 5 m. and 80 m., and between 100 m. and 200 m. I find the following mean salinities of the water-columns in the various months:

Depth.	1894.			1895.	
	April.	May.	June.	May.	July.
Between 5 m. and 80 m.	31·68	32·16	32·0	33·0	33·12
Between 100 m. and 200 m.	34·58	34·58	34·70	34·63	34·65

It will be seen that in the lower layer, between 100 m. and 200 m., the changes in the mean salinity of the water-column are only insignificant, while in the upper water-layer, between 5 m. and 80 m., the changes are relatively considerable. If the latter changes were produced merely by the formation of ice during the winter, or the melting of snow and ice on the surface during the summer, it implies that in order to reduce the mean salinity of the water-column 75 m. high, from 32·16 ‰ in May, 1894, to 32·0 ‰ in June, 1894, a layer of fresh water, about 37 cm. thick, must have been mixed with the sea-water. But in order to increase the mean salinity of the same water-column from 31·68 ‰ in April, 1894, to 33·12 ‰ in July, 1895, the formation of an ice-layer about 3·5 m. thick would be necessary. So much ice was not formed, however, in one year, according to our observations. From April, 1894, to May, 1895, an ice-floe near the Fram increased from 2·31 m. to 3·03 m. in thickness, which consequently gives the thickness of the layer of ice as no more than 0·72 m. But naturally more ice is formed on the many open lanes and channels that are formed by the movements in the ice. By the pressures, the newly-formed ice on these channels is often crushed and piled up in hummocks and ridges, and the next time the ice opens, new channels are formed, exposing a new open sea-surface to the atmosphere, thus facilitating the formation of ice. But even taking this into consideration, we cannot expect that the average thickness of the additional layer of ice formed during one year, from April, 1894, to May, 1895, on the ice-covered sea near the Fram, amounted to anything like 3·5 m.; it certainly did not exceed, say 1·5 m. The increase in the salinity of the upper water-

strata between 5 m. and 80 m., must then in great part be owing to admixture with more saline water, probably coming from the north, as explained above.[1]

The contributions of fresh-water to the North Polar Basin. Before we started on our expedition, I tried to calculate the quantity of moisture falling over that part of Siberia which has its drainage into the North Polar Basin, and I found it to be 626 cubic miles (nautical) or 3976 cubic kilometres in one year.[2] We cannot, however, expect that more than a certain percentage of this quantity of the fresh water is carried into the North Polar Sea by the Siberian rivers, as a great deal is observed by the ground, and again evaporates.

Let us, however, assume that this quantity of fresh water actually reaches the sea through the Siberian rivers during two years, and let us further assume that this fresh water has to spread only over the sea-surface extending from the Siberian coast to the North Pole, between 65° E. Long. and 165° E. Long., an area of about 3,117,000 square kilometres. The above quantity, spread uniformly over an area such as this, would form a surface-layer of fresh water about 1·276 m. in thickness. This is supposing the velocity of the current at the sea-surface is sufficient to completely renew the surface-water of the whole area in two years. If this takes four years, the thickness of the fresh-water layer would be 2·552 m.; and judging from the drift of the Jeanette and the Fram, we cannot expect it to take a longer time. Nevertheless we see that the amount of fresh water received during this period is hardly sufficient to form the ice-layer covering the North Polar Basin, which probably has an average thickness of more than 2·5 m. The precipitation falling over this sea-area itself is not very considerable. Judging from our observations, it will hardly amount to more than 0·25 m. per year, or it may perhaps reach 1 m. during four years.

If we do not consider the ice formed on the sea-surface, and suppose that all the water coming from the Siberian rivers is used to dilute the sea-

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[1] That it cannot be due to mixture with the underlying warmer Gulf Stream water is also proved by the fact that there are no such great changes in the salinity of the intervening water-strata, between 100 m. and 200 m.

[2] See 'The Forum', New York, vol. XI, 1891, p. 698. 'The Geographical Journal', vol. I, London, 1893, p. 5.

water with an original salinity of 35 ‰, and thus form the surface-layer, about 200 m. thick, covering the North Polar Basin, we find that 7952 cubic kilometres of Siberian river-water (which perhaps reaches the North Polar Sea in the course of four years) would reduce the salinity of a water-stratum, 200 m. thick, covering the above-mentioned area, from 35 ‰ to 34·56 ‰, or from 34·5 ‰ to 34·07 ‰, and from 34·0 ‰ to 33·58 ‰.

According to our observations, the mean salinity of the water-stratum from 5 m. to 200 m. was

	April 1894.	May 1894.	June 1894.	May 1895.	July 1895.
Mean salinity from 5 to 200 m.	33·26 ‰	33·48 ‰	33·47 ‰	33·88 ‰	33·95 ‰

We see that even if we assume the mean salinity found for July, 1895, to be the mean salinity of this water-stratum covering the whole area mentioned, it would be too low to be obtained by the admixture with the sea-water of the above quantity of river-water, unless we assume the original salinity of the sea-water to have been less than 34·5 ‰, which is hardly probable. It must also be remembred that in this calculation we have disregarded the quantity of fresh water which annually goes to the formation of ice, and which will amount to a good deal, even if the precipitation falling over the sea itself be subtracted.

It ought, however, to be remembered on the one hand, that the calculation of the annual quantity of water conveyed by the Siberian rivers is very doubtful and far from accurate, and on the other hand that we have assumed the entire water-stratum, 200 m. thick, of the whole area mentioned to be renewed during a period of four years, an assumption which is evidently incorrect. It is possible, judging from our observations, that the time required for the ice-covering and the uppermost surface-layers of water to traverse the above-mentioned area, may average four years or probably somewhat less; but the deeper water-strata certainly do not move with such velocity; we may assume that the velocity of the current decreases very rapidly with the depth, from 10 m. down to 200 m., where there is probably very little current. The water-strata at 100 m. for instance, or even at 50 m., certainly take much longer than the above-mentioned period to be renewed.

Thus, in spite of everything, the water from the Siberian and North American rivers may go far towards explaining the low salinity of the layer of north polar water. But the North Polar Basin also receives other contributions of water with low salinity, helping to form this layer, *e. g.* the current through Bering Strait. In 1891, I calculated the quantity of water carried by this current into the North Polar Basin to be between 10 and 14 cubic miles, *i. e.* from 64 to 89 cubic kilometres, daily; but these quantities are probably too great, providing as they do an average velocity of half a knot for the whole volume of the current continuously during the whole year. But let us assume that the current carries, on an average, 20 cubic kilometres of water daily into the North Polar Basin, which implies that the whole volume of water moves northward with a mean velocity of about 5·1 kilometres every twenty-four hours. This will consequently give us 7300 cubic kilometres in one year. The mean salinity of this water may be about 31 ‰, according to the observations of the Vega Expedition (see Pettersson, l. c., Pl. 26), and if the sea-water of low salinity be formed by diluting sea-water of 35 ‰ with fresh water, the above quantity of sea-water of 31 ‰ would represent a contribution of 834 cubic kilometres of fresh water annually to the North Polar Basin, which is evidently considerably less than the contribution received annually from the Siberian rivers.

Another contribution of fresh water may be received from the rivers of Northern Europe. The water from the Baltic and from Norway passes to some extent northward, forming a coast current along the Norwegian coast into the Barents and Murman Sea (see above, p. 258), where there is also a contribution of fresh-water from the Russian rivers, besides the precipitation over the sea itself, which is considerably greater than the evaporation. But we cannot expect the influence of these contributions to extend farther than to the western parts of the North Polar Basin.

It appears from what has been stated, that the contribution of fresh water from Siberian rivers is the chief factor in forming the layer of North Polar water with low salinity, covering the sea that was traversed by the Fram.

b. *The Gulf Stream Water of the North Polar Basin.*

From a depth of 200 or 240 m. to the bottom, the North Polar Basin is filled with water of a very uniform, high salinity, and of a relatively high temperature. This water must originate from the Atlantic Ocean.

The vertical distribution of salinity seems, according to our observations, to be very uniform in the deep water, between 250 m. and the bottom, along the whole route of the Fram, from the deep sea to the north of the New Siberian Islands to the sea north of Spitsbergen. I consider it very probable both that the salinity at the same depth, if it were greater than 250 m. or 300 m., was very nearly the same throughout that part of the North Polar Basin which was traversed by the Fram, and that there are only very slight, gradual, and relatively regular changes in the salinity from 250 m. down towards the bottom. The irregular changes in our values of the salinity of the deep water — both at the same depth from one place to another (see the Table, pp.306—307), and in the same series from one depth to another (see curves, Pls. X—XIII) — are evidently due to incidental irregularities in our observations (cf. pp. 148 *et seq.* and Memoir X), our methods of determination not being sufficiently accurate to demonstrate the slight variations which may exist. In order to get some knowledge of the changes that may occur in the salinity and density of the deep water of a sea similar to this, I carried out investigations with a high degree of accuracy at many places in the Norwegian Sea during Dr. Hjort's expedition with the *Michael Sars* to Iceland and Jan Mayen, in the summer of 1900. I found as I had expected, that below a certain depth, underneath the lower boundary of the Gulf Stream, the salinity of this sea is nearly constant, the variations at different places hardly exceeding 0·02 ‰.[1] This indicates how very conservative the conditions probably are in the deeper strata of the Ocean, and how very slowly they change. There is every reason to believe that the conditions in the deep water of the enclosed North Polar Basin are still more constant and uniform than those in the Norwegian Sea.

I have, in another paper (Memoir X), discussed the degree of accuracy that may be attained by determinations with the ordinary floating hydrometer, and have proved that errors of 0·2 ‰, or even 0·3 ‰, may easily occur in such determinations, if special precautions be not taken. When therefore

[1] See 'Nyt Magazin for Naturvidenskab', vol. 39, Christiania, 1901, pp. 129 *et seq.*

I see, for instance, that on June 26th, 1894, I found the salinity at 600 m. to be 35·33 ‰, while the next day I found it to be 35·10 ‰ at 800 m., or even 35·04 at 1200 m., I believe these great differences to be due to errors or irregularities in the determinations[1] and not to differences in the salinity of the water-strata; for we can say with certainty that such great differences do not exist in the salinity of the deep water of the North Polar Basin. And similarly, when I found 35·33 ‰ at 600 m. in June, 1894, but 35·12 ‰ at the same depth in October, 1894, and 35·13 ‰ in May, 1894, this is probably also chiefly due to irregularities in the determinations; and this is evidently the case with a difference such as between 35·33 ‰ found at 1200 m. by Tornøe's electric apparatus in May, 1894, and 35·04 ‰ found by the hydrometer at the same depth in June, 1894, etc., etc.

I think therefore that we may take the mean of all determination of the salinity made for every depth between 250 m. and the bottom, and may assume the values thus obtained to be the salinities of the deep water at the various depths of the North Polar Basin traversed by the Fram.

We see (cfr. Table pp. 306—307 last column) then that the salinity at 200 m. was generally very nerly 35 ‰, except in April and May, 1894, when it was 34·75 ‰ with low temperatures. At 250 m. the salinity had increased to about 35·1 ‰. Between 350 m. and 400 m. it was about 35·2 ‰, and from this depth down towards the bottom; it remained very nearly the same, or perhaps increased upon the whole quite gradually to about 35·25 ‰.

But if we assume, as we are evidently justified in doing, that the salinity of the water at depths between 400 m. and the bottom was very nearly the same in the sea traversed by the Fram between April, 1894, and July, 1895, it is within our power to find out more accurately than above what this salinity has been. I have already (p. 148, foot-note 2) stated that the correction of the hydrometer Åderman No. 2 cannot possibly have been higher than + 0·00081 (at maximum of surface-tension of the water-sample), and not lower than + 0·00040 (at minimum of surface-tension) at indications of the instrument of about 1·02600 and 1·02700. At indicications of about 1·02800, the corrections will be + 0·00080 and + 0·00039 (cf. p. 150). Only in one exceptional case

[1] There may either have been differences in the surface-tension of the water-samples, affecting the hydrometer, or the water-bottle may not have worked perfectly, and may have given inaccurate water-samples, although this is less probable.

did I find the correction of the hydrometer to be as low as + 0·00035 (see p. 149, foot-note). If, therefore, amongst the hundreds of observations made with Åderman No. 2, we pick out those which, referred to 17·5° C. (see Table, pp. 169 *et. seq.* 7th column), give the highest and lowest values, and correct these with the lowest and highest corrections of the instrument, we find the lower and upper possible limit of $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$ and the salinity. In the following table I have collected the observations best suited for this purpose.

Date.	Depth in m.	Reading referred to 17·5° C.	Correction.	Lower Limit.		Upper Limit.	
				$S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$	‰	$S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$	‰
Nov. 2, 1894	310	1·02604	+ 81			1·02685	35·31
	310	2627	+ 40	1·02667	35·08		
Oct. 18, —	400	2639	+ 39	2678	35·22		
June 26, —	450	2639	+ 39 [1]	2678	35·22		
Oct. 18, —	450	2650	+ 35	2685	35·31		
June 26, —	600	2638	+ 39	2677	35·20		
Nov. 3, —	700	2604	+ 81			2685	35·31
July 31, 1895	900	2607	+ 81			2688	35·35
„ 25, —	1000	2640	+ 40	2680	35·24		
„ „ —	1100	2648	+ 35	2683	35·28		
June 27, 1894	1200	2604	+ 80			2684	35·29
July 25, 1895	1200	2639	+ 40	2679	35·23		
April 26, 1894	1400	2649	+ 35	2684	35·29		
Oct. 27, —	2500	2640	+ 39	2679	35·23		
„ 29, —	3000	2649	+ 35	2684	35·29		

We see that while at 310 m. the salinity may be between 35·08 ‰ and 35·31 ‰, the lower possible limit at depths greater than 400 m. is about 35·22 ‰, while the upper possible limit is from 35·29 ‰ to 35·35 ‰. As the lowest value found of the upper limit is 35·29 ‰, at 1200 m., and the highest value of the lower limit is 35·31 ‰, at 450 m. and 35·29 ‰ at 1400 m. and 3000 m., we may assume with a high degree of certainty that *the salinity has, as a rule, been about* **35·29** ‰ *at all depths greater than 450 m.*, and the variations in this salinity of the deep water have evidently

[1] As this reading was taken after the stem had been wiped and the hydrometer had been left floating in the water-sample for some time undisturbed (see p. 176), we may be certain that the correction cannot have been lower in this case (cf. X, pp. 38, 43), and we thus obtain the absolute lower limit of $S\frac{17{\cdot}5^\circ\,\mathrm{C.}}{17{\cdot}5^\circ\,\mathrm{C.}}$

been so small, that they could not have been demonstrated with our methods of determination.

The salinities of the water-samples taken by Dr. Blessing on November 30th and December 2nd, 1895, and brought home, were lower than this, the salinity of the samples from 800, 850, and 900 m. being about 35·15 ‰ (see p. 214). But the Blessing water-bottle does not seem to have worked quite perfectly on this date; it probably did not close quite tightly, and in one case, the water-sample from 1900 m., it was evidently closed at a wrong depth. We cannot, therefore, ascribe much value to the determinations of these water-samples in our attempt to arrive at some trustworthy conclusion as to the salinity of the deep water of the North Polar Basin.

Vertical and horizontal distribution of temperature. While we have found that the salinity of the deep water was evidently very uniformly distributed, both vertically and horizontally, and with very slight variations, we find that this is not the case to the same extent with the temperature. We see that all our curves of temperature (Pls. X—XIII) have nearly the same shape, but the maximum of temperature increases in value towards the north-west, and is situated nearer the surface in the western part of the Fram's route than in the eastern part; and similarly the thickness of the water-stratum with temperatures above 0° C., increases westward. This may easily be seen in the following table:

	1894					
	Stat. **14** April	Stat. **15** May	Stat. **16** June	Stat. **18** August [1]	Stat. **19** Oct.	Stat. **20** Nov.
Depth of upper 0° C.	215 m.	250 m.	230 m.	230 m.	[170 m.]	[165 m.]
Maximum of Temperature	0·36° C.	0·35° C.	0·40° C.	0·32° C.	0·79° C.	0·78° C.
Depth of Max. of Temp.	450 m.	440 m.	450 m.	450 m.	300 m.	310 m.
Depth of lower 0° C.	[770 m.]	740 m.	810 m.	820 m.	[835 m.]	[820 m.]

	1895			1896	
	Stat. **22** May	Stat. **23** July	Stat. **24** Nov.	Stat. **25** Febr.	Stat. **26** April
Depth of upper 0° C.	165 m.	175 m.	195 m.	195 m.	190 m.
Maximum of Temperature	1·13° C.	1·19° C.	0·8° C. ?	?	?
Depth of Max. of Temp.	325 m.	325 m.	325 m. ?		
Depth of lower 0° C.	835 m.	845 m.	850 m.	870 m.	910 m.

[1] This Station (No. 18) was situated between Stat. 14, April, 1894, and Stat. 15, May, 1894.

The figures between brackets are found by the diagrammatic curves (Pls. X—XIII) and by estimation.

We see that while the depth of the upper boundary of the water with temperatures above 0° C. varies somewhat between 250 m. and 165 m., its lower boundary sinks upon the whole, with slight undulations, considerably from Stations 14 and 15 (April and May, 1894) to Stats. 25 and 26 (February and April, 1896). The reason is evidently that the Fram in 1896 was nearer to the place where this relatively warm water with high salinity flows into the North Polar Basin. I think there is little doubt that this water originates from the branch of the Gulf Stream which flows northward along the west coast of Spitsbergen.

The origin and course of the warm under-current is, in my opinion, the following: The upper layers of the Gulf Stream to the north of Norway, as already stated, (p. 258) are, by the Earth's rotation, skimmed off and forced eastward past the North Cape into the Barents Sea. The deeper layers of the Gulf Stream, deeper than 200 and 300 m., are prevented by the suboceanic platform, uniting Norway with Spitsbergen, from taking this course, and in spite of the great force with which the Earth's rotation carries moving water towards the right in these high latitudes,[1] this deep Gulf Stream water must follow the western edge of the platform northward, west of Bear Island, and along the west coast of Spitsbergen. But on account of the Earth's rotation, the water of the current is continually pressed eastward against the edge of the platform, and against the west coast of Spitsbergen, and the result is that the current has a strong tendency to become narrower in width, but at the same time deeper and higher, with a continuous tendency to again reach the surface of the sea; and therefore, although this partly sunken current, may, to a great extent, be covered by polar water along the west coast of Spitsbergen, we

[1] *E. g.* A water-particle moving in a certain direction with a velocity of 10 kilometres in 24 hours will, owing to the Earth's rotation, have a tendency to be displaced 59 kilometres towards the right in 70° N. Lat., and 61·9 kilometres towards the right in 80° N. Lat. in the same period, the friction etc. not being considered.

The reason why the surface layers of the northward flowing current ('Gulf Stream') does not run with still greater force into the Barents and Murman Sea, is evidently that the sea bottom rises so steeply from the abyssal region of the Norwegian Sea to form the continental slope between Norway and Bear Island. As is pointed out elsewhere (p. 260, see also my paper in Nyt Mag. for Naturvidensk. vol. 39, 1901, p. 152) the form of the sea bottom greatly influences the direction and velocity even of the surface currents.

may occasionally at certain places suddenly meet with local patches of surface-water with much higher salinity than that of the surrounding sea. When the current reaches the north-west corner of Spitsbergen, it is lifted and forced towards the surface by the comparatively shallow suboceanic ridge running from Spitsbergen towards the north-west, and this is evidently the reason why a patch with a higher surface-salinity and a higher surface-temperature has sometimes been found exactly at this place, *e. g.* by the Norwegian North Atlantic Expedition in 1878. Already on his chart of 1870, Petermann indicated a patch of warmer surface water west of Spitsbergen, in 79° N. Lat. (Petermann's Mitteilungen, 1870).

Thirty-five miles (65 kilometres) from Spitsbergen the depth of this ridge is 475 m. (260 fathoms), and 60 miles (111 kilometres) from Spitsbergen is 840 m. (459 fathoms).[1] In about 81° N. Lat. and 4° E. Long., the depth was found to be about 786 m. (430 fathoms). How far this suboceanic ridge extends towards the north-west or west is not known, but, as will be mentioned later, there is a probability that it unites Spitsbergen with Greenland.

The Gulf Stream flows across this ridge near to the Spitsbergen coast, its western boundary being perhaps 80 miles (150 kilometres) from land, and the depth of its lower boundary being perhaps from 700 to 800 m.

After having passed the ridge, the Gulf Stream flows north-east into the North Polar Basin where it gradually sinks under the surface-layer of polar water, which is much lighter on account of its low salinity. By the Earth's rotation, the Gulf Stream water is forced eastward in the North Polar Basin, and will probably pass close along the edge (the continental slope) of the continental shelf extending north from Europe and Siberia, north of Spitsbergen, Franz Josef Land and the New Siberian Islands, and forming the southern boundary of the deep depression of the North Polar Basin.

If this be correct, we may expect to find the warm under-current comparatively thick near the continental slope, and less developed farther north. The Fram observations give actually indications in this direction. Being situated relatively far south, Stats. 19, 20, and 23 are probably nearer to the continental slope (north of Cape Chelyuskin and the Franz Josef Archipelago) than the other Stations; and there the water layer with a temperature above

[1] See Mohn, 'The North Ocean', etc. 'The Norwegian North Atlantic Expedition' 1876—78, Kristiania, 1887, Pl. 1.

0·5° C. is comparatively thick (cf. the form of the isotherms of 0·5° C. and 1° C., Pl. XV) while it is strikingly thin at Stat. 24, the most northern Station, and is suddenly totally absent east of Stat. 19. Stats. 19, 20, and 23 have probably been situated nearer to the axis of the warm under-current, while the other Stations have been situated more on its north side. The thickness of the overlying cold water-stratum exhibits similar variations, as mentioned on p. 305.

During its eastward course in the North Polar Basin, the warm water of the Gulf Stream is gradually cooled down by the loss of heat given off especially to the overlying cold water-stratum but also to the underlying water. The details of this cooling will be discussed later on. This is evidently the reason why we found the maximum of temperature decreasing eastward, and situated deeper there than in the western part of the sea northeast of Franz Josef Land, and also why the thickness of the water-stratum with temperatures above 0° C. upon the whole decreases towards the east, as we have seen.[1]

The sections on Pls. XIV and XV give a clear illustration of the eastward cooling of the warm water coming from the west, the isotherms of 0·5° C. and 1° C. forming tongues. These tongues, however, do not decrease quite regularly in thickness from west to east in our section, but this may, as just mentioned, be explained by the differences in the distances of the Stations from the continental slope.

There may of course also be local irregularities in the warm under-current. If, for instance, the influx of warm water west of Spitsbergen, be subject to irregular or periodical changes at different seasons or even different years, as is highly probable, the result must be that the warm under-current may differ in thickness and temperature, and even in salinity, in various parts of the North Polar Basin. If, for instance, the water-samples taken up with the water-bottle from the warm under-current at Stat. 23 (July, 1895),

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[1] *Petermann* believed in 1870 (Petermann's Mitteilungen, 1870, pp. 201, 226, 228) the North Cape current to be the main branch of the Gulf Stream, carrying much warm wather into the North Polar Sea, and even causing the 'polynja's' of the Russian travellers north of the New Siberian Islands(!). Before we started on our expedition, I believed the North Cape Current entering the Barents Sea to bring the most important contribution of water to the North Polar Sea; but our observations seem to prove that only very little water from this current actually enters the deep North Polar Basin, which, according to what is stated above (p. 288), must be separated from the Barents Sea by some shallow ridge or plateau uniting Siberia with Franz Josef Land.

belonged to water which had passed the suboceanic ridge north-west of Spitsbergen four years earlier, in the summer of 1891, and if at that time the Gulf Stream west of Spitsbergen was well developed, we would find the warm under-current relatively thick and with relatively high temperatures and salinities at Stat. 23, and *vice versa*.

The periodical changes in the Gulf Stream west of Spitsbergen may thus be repeated as undulations in the form of the isotherms and the isohalines of the warm under-current in the North Polar Basin. It seems difficult to decide whether the undulations of the isotherms of 0° C., —0·25° C., —0·5°C., —0·75° C. and —1° C. at Stations 19, 16, 15, and 18 may be thus explained, or whether they may not rather have had other causes, (*e. g.* the situation of the stations, and the form of the bottom). The course of the isotherms of —0·5° C. and —0·75° C. at about 1400 m. and 2000 m. is at any rate evidently influenced by the bottom; at Stat. 18 we have a distinct depression in both lines corresponding to the depression in the bottom. This depression is most distinct in the lowest isotherm, at 2200 m., where it is more than 200 m., deep; and it regularly decreases upward in the isotherms at smaller depths, until it is hardly traceable in the isotherm of 0° C. at 800 m. This circumstance seems to make it still more probable that we here actually have some influence exercised by the form of the bottom.[1] The isotherms of 0° C. and —1° C. at 230 m. and 150 m. have rather a slight elevation at Stat. 18 instead of the depression at greater depths. At Stat. 15, there is a distinct depression of the upper isotherms of —1° C., —0·5° C., and 0° C. (Pl. XV), while there is an elevation in the lower isotherms of 0° C. and —0·25° C. (Pl. XIV). Simultaneously there is a depression of the isohaline of 34·75 ‰ and a marked elevation of the isohaline of 35·2 ‰ at Stats. 15 and 16. These variations seem to be greater than can be explained by accidental irregularities in the observations; and they seem to indicate that the stratum of warm water with relatively high salinity has been considerably thinner at Stat. 15, and to some extent at Stat. 16, than at the other stations. The explanation is probably that Stats. 15 and 16 were situated comparatively far north and farther away from the continental slope.

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[1] Cf. what I say about the influence of the configuration of the sea-bed upon the currents in 'Nyt Magazin for Naturvidenskab.', vol. 39, Christiania, 1901, p. 152.

In the deeper part of the Basin, at depths below 1000 m., there is evidently great uniformity in the temperature, which sinks quite regularly and gradually with the increasing depth. It seems, however, as if the temperature of this deeper strata, upon the whole, were lower in the western part of the Basin than in its eastern part (see Table, pp. 306—307). The temperature of the water at 1000 m., for instance, was from —0·11° C. to —0·16° C. from April to August, 1894 (Stats. 14 to 16 and 18; see Section, Pl. XIV), while it was —0·25° C. and —0·23° C. in October and November, 1894, (Stats. 19, 20), and in May and July, 1895 (Stats. 22, 23) it was —0·23° C. and —0·33° C. At 1200 m. the temperature was —0·32° C. at Stations 14, 18, and 15. Farther west it was —0·34° C. at Stat. 16, —0·40° C. at Stat. 22, and —0·49° C. at Stat. 23 (see Pl. XIV). These differences seem too great and also too regular to be due to inaccuracies in the determinations. At greater depths we find to some extent similar changes in the temperature, *e. g.* at 3000 m. the temperature was —0·78° C. in August, 1894 (Stat. 18), —0·84 in October, 1894, (Stat. 19), and —0·87° C. in April, 1896, (Stat. 26), north of Spitsbergen. We see consequently that the temperature of the deeper strata, below 1000 m., appears upon the whole to decrease quite slowly from the east towards the west, *i. e.* in the opposite direction of the warm water between 250 m. and 800 m., and this circumstance may perhaps give some indication with regard to the circulation of this water, as we shall presently see.

What is the origin of this cold underlying water? It cannot possibly have been cooled down to its lower temperature in its present position, for the water overlying it is warmer, and underneath is the sea-bottom, which at that depth must have a higher temperature than the water on account of the subterranean heat. We have probably also directly observed the effect of this higher temperature of the bottom, as a slowly rising temperature below 2800 m. (see later). We are thus obliged to assume that this colder water originates from some other part of the North Polar Basin where the overlying warmer water has been cooled down to this lower temperature. I think the explanation might be the following: The originally warm and saline Gulf Stream water flowing into the North Polar Basin, is forced, on account of the Earth's rotation, to the right, and cannot therefore at once, north of Spitsbergen, spread under the polar water and fill the whole Basin, but will, as before

mentioned, in the main pass eastward along the edge or the continental slope of the Eurasian continental shelf, and flowing continually eastward will follow the configuration of this slope round the whole Basin, first along the Siberian side, and then along the American side, until the circumpolar circulation is more or less completed. But during its course, the water, as we have seen, is gradually cooled down. Northwest of Spitsbergen the maximum temperature of the Gulf Stream water is probably 3° C. or 4° C. situated perhaps at about 100 m. Northeast of Franz Josef Land, in 84° 32′ N. and about 74° E. (St. 23), the maximum of temperature was 1·19° C. situated at about 350 m. North of the New Siberian Islands (Stat. 14) it was 0·36° C. at about 450 m. The decrease of the temperature of the water during its eastward course must evidently be quite regularly asymptotic, and we may expect to find the maximum of temperature to be below 0° C. at about 500 m. or 550 m. in the meridian of Bering Strait, and perhaps in about 79° or 78° N. Lat. Still farther eastward on the American side the temperature will be still lower, but the decrease will be continually smaller and smaller as the temperature will approach asymptotically that of the overlying cold water.[1]

The cooling of the water may be effected in several ways. (1) At the contact with the overlying cold polar water there will be a certain amount of mixing, but this will diminish not only the temperature, but also the salinity of the water. We have seen some effect of this admixture in the increase, towards the west, of the salinity and the temperature of the polar water

[1] The maximum temperature of the Gulf Stream between Shetland and the Færoe Islands is at least 9° C. or 10° C. (perhaps 11° C. or 12° C.). Its temperature is consequently cooled down at least 6° C. from this place to Spitsbergen, and thence to north of the New Siberian Islands the cooling is about 3° C. The distance travelled is about the same in both cases.

O. Pettersson and *G. Ekman* maintain (Bihang till K. Svenska. Vet.-Akad. Handl. vol. 23, No. 4, 1898, p. 21) that the velocity of the sunken warm current is greatly retarded by the „ungemein vermehrte“ friction, and its cooling down is much increased by the loss of heat given off to the ice-cold overlying water-strata where melting also occurs. I think on the one hand it is very doubtful whether the inner friction of the sea-water is as great as the two authors seem prone to believe, and on the other hand the overlying cold but light water stratum in the North Polar Basin rather reduces the cooling of the warmer under-current, protecting it against the loss of heat by emission. In this sea there is also much more freezing of ice than melting, and latent heat is thus set free. It should also be remembered that an under-current runs quietly without being agitated by winds on its surface, and, as we have seen, it is but little mixed with the overlying lighter water, except in a relatively thin upper layer. The result is, as we have seen, a very slow cooling; from northeast of Franz Josef Land to north of the New Siberian Islands the cooling is only about 0·8° C.

at 180 m. and 200 m. The effect of this admixture will not, however, go deep.

(2) Near the contact with the overlying cold water, the warm saline water will also be cooled down, by conduction and emission of heat, without changing its salinity. As it will thus obtain a higher density, it will gradually sink and be replaced by water from the underlying stratum. In this manner a slow cooling of the whole warm stratum may finally be effected.

But the warm water is probably not only in contact with colder water at its upper boundary; the water on the left side of the current, *i. e.*, towards the north, must, according to what has been said, have a lower temperature than the warm water observed by us, and therefore on the left side of the current there is probably also a slight cooling, the water thus cooled having a tendency to sink and to flow in under the warmer water to the right, which will take its place. Thus a kind of spiral movement must be produced along the current. This cooling, however, must be relatively insignificant, as there is probably only a very slow and quite gradual transition from our warm water to the colder water to the north. The temperature of the warm water will naturally also be lowered by mixing with the underlying colder water, but as this cooling is only of secondary origin, we do not need to consider it here.[1] The most important cooling is of course that produced by the contact with the overlying cold water. The originally warm and saline water, which has thus been cooled down without having changed its salinity, will become heavier and will gradually sink during the eastward course of the warm current, and must finally fill the bottom of the basin with colder water. But from this gradual sinking, we might expect that the deep water along the eastern part of the Fram's route, north of the New Siberian Islands, would have a somewhat higher temperature than the deep water north of Franz Josef Land or Spitsbergen, just as we have found to be the case; for the water that sinks in the former part of the sea has not been so much cooled as the water that, after having almost completed its circumpolar course along the edges of the basin, sinks at the north of Greenland, in order to form the bottom water of the sea north of Spitsbergen and Franz Josef Land.

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[1] The cooling effected from beneath by conduction of heat is evidently insignificant; it is also of secondary origin and may be disregarded here.

The sinking, heavy water thus produced probably takes a very complicated course, as the movement is evidently very slow, and may easily be influenced by various forces, *e. g.* the friction of the overlying water, the Earths's rotation, etc. It seems, however, probable that the final result of the whole process would be a spiral current in the great depths of the North Polar Basin; for when the water of the warm under-current again reaches the region north of Spitsbergen after having completed its first circumpolar circuit along the edges of the continental shelf, it may have become so heavy by the cooling, that a great part of it sinks under the inflowing warm water and forms a deeper or bottom current circulating in the same direction as the overlying warm water. But during its eastward course, the water of this bottom current will be slowly heated by the overlying warmer water, and still more by the sea-bed, owing to the subterranean heat (see later). The final result of this heating must be that the bottom water will at last again rise, probably before it has been able to complete a second rotation in the basin.

According to what is stated above, the intermediate warm current may have a thickness of say 600 or 700 m. A great deal of the water of this current is again carried directly out of the North Polar Basin by the Polar surface current, and only a part of the water may be left to form the bottom current. As the thickness of the latter may be about 2500 m., it is evident that its velocity can only be a small fraction of that of the overlying warm current.

We might naturally expect this deep water to have an extremely slow circulation, and to be renewed only after a long series of years. If there is a suboceanic ridge between Spitsbergen and Greenland, as I think we are obliged to assume, the water can only be carried slowly out of the deep North Polar Basin, by the friction with the overlying, finally outward-flowing water with which it is thus to some slight extent mixed.

We have found that the water at the surface probably recquires four or five years to cross the North Polar Basin, and that the water somewhat deeper at 50 or 100 m. requires a much longer period to be renewed. But the deep water evidently requires many times again this latter period to be renewed; and it may be, therefore, that we still find water in the deeper strata of the North Polar Basin, which was carried into it hundreds of years

ago, if this be not prevented by the heating of the bottom water by the subterranean heat.

The rise of temperature towards the bottom of the North Polar Basin. In our series of temperatures taken in August, 1894, there is a very slight, but distinct and quite regular, rise in the temperatures from the depth of 2900 m., where there was a minimum of —0·81° C., towards the bottom where the temperature was —0·69° C. at 3800 m. (the bottom being at a depth of between 3800 m. and 3900 m.). This series is the only one which reached sufficiently deep with observations at regular intervals, to give quite trustworthy information of this rise in temperature. The series taken in October, 1894, containing observations at 2000 m., 2500 m., and 3000 m. seems, however, also to indicate a similar rise in temperature from 2500 m. towards the bottom at about 3350 m. Owing to the low temperature of the atmosphere, the observations taken on this date, especially at 2500 m. are not very accurate (see Table, p. 252, and foot-note); but as the determination of the temperature at 3000 m. is higher even than the temperature at 2000 m., it seems probable that there has actually been a rise towards the bottom also on this date.

The observations taken in August, 1894, are at any rate so trustworthy that we can determine the rise in temperature towards the bottom with a fair degree of accuracy. We find it to be 0·13° C. in 900 m. (from 2900 m. to 3800 m.). Whether there was a corresponding rise in the salinity cannot be decided, as no water-samples were taken from depths below 3000 m.[1]; but even if this had been the case, our method of determination was not, as already mentioned, sufficiently accurate to show differences in salinity so minute as these would at any rate be. We may assume with certainty that the salinity of the strata near the bottom has been very nearly the same as that of the overlying strata (i. e. about 35·3‰).

What may be the origin of the rising temperature towards the bottom? As the water is exposed to greater pressure by sinking, its temperature is somewhat increased by the compression. But a sinking of 900 m. of water with a temperature of —0·81° C. would only increase the temperature about 0·02° C.

[1] As our sounding line was not very strong, I would not risk my Pettersson water-bottle by sending it down to such depths, as there was a possibility of the line breaking.

I can find no other satisfactory explanation than that we have here an effect of the higher temperature of the sea-bottom, owing to conduction of heat from the interior of the lithosphere. Chemical processes in the deposits of the sea-bottom would naturally also increase its temperature. But there is probably very little chemical decomposition in the deep-sea deposits of the North Polar Basin, which consist chiefly of mineral matter.

I believe, therefore, that we have here actually an effect of the subterranean heat. By examining the series of deep-sea temperatures of other expeditions, I believe I find in several places indications of a similar rise of temperature towards the bottom, where the depths are great and the temperature near the bottom very low, and also where the deep sea-basin is more or less enclosed. We cannot expect to find it to the same extent in more open sea-basins with a relatively high bottom-temperature, for the circulation along the bottom is there more active, and at higher temperatures the density of the water is more changed by changes in the temperature, and the water heated by the bottom will therefore rise more rapidly. The Norwegian Sea may be considered as an enclosed sea-basin, which, especially in its northern part, has a very low bottom-temperature, and we might therefore expect to find a similar rise in the temperature near the bottom there. Unfortunately we have very few soundings with temperature-observations from the strata near the bottom of this part of the sea. During the Norwegian North Atlantic Expedition, a sounding was taken at Station 304, in the deep basin between Bear Island and Greenland (July 20th, 1878), which gave —1·6° C. at 2624 m. (1435 fathoms) and —1·5° C. at the bottom in 3173 m. (1735 fathoms).[1] Mohn has, however, evidently considered the observation at 2624 m. as doubtful, for in his Table (l. c., p. 56, column 11) he has corrected both temperatures to —1·5° C. At Station 350, midway between South Cape on Spitsbergen and Greenland, —1·54° C. was observed at 2533 m., and about —1·53° C. at 3083 m. (bottom). These were the only observations taken at depths near the bottom in this northern deep part of the sea with very low bottom-temperatures. At Station 183, midway between Lofoten and Jan Mayen, —1·20° C. was observed at 2560 m., and about —1·27° C. at the bottom in 3127 m. Even if the above observations cannot be assumed to be absolutely accurate, they

[1] See Mohn, l. c., p. 56, column 10, Pls. VI and XII.

seem, nevertheless, to indicate that there may be a slight rise in the temperature towards the bottom in the deepest strata of the northern part of the Norwegian Sea, or that the changes in temperature are at any rate very slight in these strata.

In the series of deep-sea temperatures of the Danish Ingolf Expedition taken in the sea near Iceland, there is also an evident tendency towards great uniformity in the temperature near the bottom. At station 113, for instance, the same temperature of —1·0° C. was observed at 1506 m. and at the bottom in 2465 m.[1]

During my observations in the Norwegian Sea with Dr. Hjort in the summer of 1900, we found no distinct rise in the temperature towards the bottom; but the change in temperature was very slight in the deepest strata. In 63° 53′ N. and 6° 22′ E. we found for instance —1·09° C. at 1800 m., —1·14° C. at 2030 m., and —1·12° C. at 2100 m. The bottom was at 2134 m. West of Jan Mayen in about 70° 20′ N., 2° 30′ E., we found —1·16° C. at 2000 m., —1·18° C. at 2300 m., and —1·19° C. at the bottom, 2750 m. It must, however, be remembered that we obtained no observations from the deepest part of this basin.

It is quite clear that the subterranean heat must have some raising effect upon the temperature of the water-strata near the bottom of the deep sea. We may suppose that the underground temperature increases somewhat more rapidly with the depth under the bottom of a sea 3800 m. deep, than it does under the surface of the continents at sea level. We have no means at present of calculating the rate of the increase of the temperature under the sea, nor do we know what the thermal conductivity of the rocks under the sea may be, but it is probably greater than that of the surface of continents. Let us for the sake of simplicity suppose that the temperature increases 1° C. per 30 m., and that the thermal conductivity in centimetre-gramme-minute is 0·6 (the conductivity of granite is 0·585).

Thus the quantity of heat conducted through a square centimetre of the sea-bottom would be, in one year,

$$\frac{525960}{3000} \times 0{\cdot}6 = 105{\cdot}192 \text{ gramme-calories.}$$

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[1] M. Knudsen l. c., p. 78, cf. also the shape of his temperature curves, Pls. XIII—XVI

Or if we use kilogramme-calories, we find that 1052 kilogramme-calories should be conducted through every square metre of the sea-bottom yearly, and this quantity of heat would be sufficient to raise the temperature of a water-stratum, 100 m. thick, near the sea-bottom, about 0·01° C. in one year.[1] If the stratum thus heated be of the same salinity as the overlying water, the result will be that the underlying water will rise slowly, as its density has become a trifle lower than that of the overlying water.[2] If the rising current, thus produced, be relatively more rapid than the conduction of heat, the result may be that the strata of the sea beneath a certain depth near the bottom, will acquire a nearly uniform temperature, as seems often to be the case in the ocean. But if the rising current be slower, the temperature of the deepest strata will increase quite slowly towards the bottom.

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[1] Acccording to Lord *Kelvin's* calculation, about 580 kilogramme-calories should be conducted to every square metre of the Earth's surface yearly (see Sir William Thomson, 'Polar Ice-Caps and their influence in changing sea levels', Transactions of the Geological Society of Glasgow, Febr., 1888, p. 340).

Prof. *O. E. Schiötz* has found the quantity of heat to be 603 calories yearly ('Das Schmelzen des Binneneises', Christiania Videnskabs-Selskabs Forhandl., 1891, No. 6, p. 12.

Dr. *F. A. Forel* states in his 'Handbuch der Seenkunde' (Stuttgart, 1901, p. 122) that the subterranean heat may be able to raise the temperature of a water-stratum, 100 m. thick, 0·004° C. in one year.

It has been pointed out by several authors that the subterranean heat may have some effect upon the temperature of the deepest water-strata in lakes. Cf. *O. E. Schötz*, 'Resultatet af en Del Undersøgelser over Temperaturforholdene i Dybet af Mjøsen', Forhandl. ved de skandinaviske Naturforskeres 13de Møde, Christiania, 1887, p. 64. *E. Richter*, 'Die Temperaturverhältnisse der Alpenseen', Verhandl. des IX deutschen Geographentages zu Wien, Berlin, 1891, p. 196. *Idem,* 'Seestudien', Geographische Abhandlungen herausgegeben von Penck in Wien, vol. VI, Part 2, p. 69, etc.

[2] It of course makes no difference in this respect that the underlying water is more compressed by the pressure, and may have a somewhat higher density *in situ* than the overlying water; for if a water-particle that has been thus heated, be moved upwards only a millimetre, it will become lighter than the surrounding water-particles and will rise, and thus the equilibrium will be disturbed at once.

M. Knudsen says about the densities in the sea near Iceland (l. c., p. 103): "When the depth is great, $S\,\frac{t}{4}$ will generally decrease in the lowermost strata. It should be remembered, however, that $S\,\frac{t}{4}$ does not mean the specific gravity of the sea-water *in situ*, as the specific gravity — — — is increasing when the depth is getting larger". He evidently means that the density of the water *in situ* is increased by the compression, and that this may be able to produce equilibrium even though $S\,\frac{t}{4}$ of the underlying water be lower than that of the overlying. An assumption such as this is, as we have seen, not correct, and it may be doubted whether the apparent decrease in density towards the bottom may not be due to irregularities in the observations.

In a sea where the salinity of the deeper water-strata slowly rises with the nearer approach to the bottom, the deepest strata may be somewhat heated without becoming lighter than the overlying water, and may remain in position. If there were only an extremely slow circulation, we might in such a sea find the temperature rising with the depth as rapidly as the increase of salinity would allow without disturbing the equilibrium. A rise in temperature from —0·81° C. to —0·69° C., as in the North Polar Basin, would thus necessitate an increase in the salinity, *e. g.* from 35·290 ‰ to 35·296 ‰, if the equilibrium is to be perfect. But if the underlying water-strata be heated more than is consistent with the maintenance of equilibrium, as they naturally will be in course of time, if not prevented by circulation, an ascending current will finally be produced in spite of the increasing salinity downward.

We thus see that the final effect of the subterranean heat in a sea with very slow circulation near the bottom, must be an ascending current in the bottom layers; and if we assume, for instance, that the bottom water of an enclosed deep sea such as the North Polar Basin, requires hundreds of years to be renewed, this effect of the underground temperature may be of importance for the circulation of its deepest water-strata. In 100 years the subterranean heat may have raised the temperature of the deepest 100 m. of water 1° C., or if we take the deepest 1000 m. of water, the temperature may be raised 1° C. in a thousand years. If we only accept Forel's calculation, the rise in temperature will be 0·4° C. in a thousand years; but even this is sufficient to be of much importance for the circulation of the deep water of a basin; and there will thus be a certain lower limit, below which the rate of this circulation cannot possibly sink. It seems evident that the subterranean heat may also be of importance for the circulation of the bottom-water of the great Ocean.

The constant rise of heated water from the bottom of a sea like the North Polar Basin, will also evidently have a tendency to make the salinity of the deeper water-strata very uniform, probably with a slight increase downward in the deepest strata.

But even without an increasing salinity downward, there may perhaps to some extent be equilibrium with a temperature slightly increasing towards the bottom; for it is possible that the deepest strata of a sea with uniform salinity near the bottom, contain more suspended matter than the overlying

water, and this may make the deepest strata heavier, in spite of the higher temperature.

We have thus, in our discussion of the distribution of salinity and temperature in the North Polar Basin, arrived at the conclusion that there are at least four systems of currents in a vertical section from the surface to the bottom, along the route of the Fram, viz.

(1) A surface-current of water with low salinity (from about 29 ‰ to about 32 ‰), perhaps 20 or 30 m. deep, running towards the north-west and west;

(2) An underlying, slow current of water with a higher salinity and a very low temperature, running in a different direction, and consisting of surface water from other parts of the Polar Sea. The absolute minimum of temperature is situated in this current, at about 50 or 60 m.;

(3) A current of relatively warm water with salinities of from 35·1 ‰ to 35·3 ‰, coming from the Gulf Stream west of Spitsbergen, and running towards the east at depths below 250 m., the maximum of temperature being situated in the water of this current at depths of from 350 to 450 m.; and

(4) An extremely slow current of colder water, filling the deepest part of the basin between 900 m. or 1000 m. and the bottom. This water is the heaviest water of the preceding current, which has been cooled down and has sunk towards the bottom; it has a salinity of about 35·29 ‰. It is possible that this water forms to some extent a spiral current under the preceding current, running in a similar direction.

c. *Oscillations of the Boundary between the Cold Surface-Current and the Warmer Under-Current.*

During my several series of observations, I regularly noticed that the temperature-readings taken at intervals of time from the same depths between 200 and 300 m. at the same Station varied much, while they were generally very nearly the same at all other depths (see Table, pp. 111 *et seq.*) Thinking that there might possibly be some irregularities in the observations, they were several times repeated, but with the same results. Only in some few cases when the observations were taken at very short intervals of time (*e. g.* from 250 and 275 m. on June 25th, 1894, see Table below) did I obtain the same temperature readings. The fact that different observations taken from the same

depths always give nearly the same results if the depths be less than 200 m. (cf. April 15th) or 180 m. (cf. July 29th), or greater than 300 m. (cf. April 23rd) or 350 m. (cf. June 26th and 27th, 1894, and July 29th, 1895), evidently proves that the observations are fairly trustworthy. Thus I understood that there were actually oscillations of some kind in the boundary between the overlying, cold, polar water and the underlying, warm, Gulf Stream water.

In the following table I give observations taken at the same depths in April, June, and August, 1894, and July, 1895, (cf. the tables on pp. 111 *et seq.* and pp. 246 *et seq.*):

Date 1894	Depth in Metres	Instrument	Final Value of Temp. Reading	Mean of Simultan. Observat.
	m.		° C.	° C.
April 15	140	Wat. Bot.	−1·20	−1·24
		82	−1·28	
		84	−1·26	−1·26
	160	Wat. Bot.	−0·87	−0·87
		82	−0·86	
	180	Wat. Bot.	−0·31	−0·31
		82	−0·31	
		84	−0·29	−0·29
	200	Wat. Bot.	−0·23	−0·16
		82	−0·08	
April 23		84	−0·34	−0·34
April 15	250	Wat. Bot.	0·49	0·51
		82	0·52	
April 21		Wat. Bot.	0·06	0·07
		82	0·08	
April 23		Wat. Bot.	0·12	0·09
		82	0·05	
		84	0·35	0·35
		84	0·15	0·15
	300	Wat. Bot.	0·25	0·26
		82	0·26	
		Wat. Bot.	0·25	0·27
		82	0·28	
	400	Wat. Bot.	0·37	0·36
		82	0·34	

Date 1894	Depth in Metres	Instrument	Final Value of Temp. Reading	Mean of Simultan. Observat.
	m.		° C.	° C.
June 25	160	Wat. Bot.	−0·69	−0·68
		82	−0·67	
	180	Wat. Bot.	−0·38	−0·35
		82	−0·32	
	200	Wat. Bot.	−0·27	−0·27
		82	−0·26	
	225	Wat. Bot.	−0·05	−0·05
		82	−0·04	
June 26		Wat. Bot.	−0·07	−0·05
		82	−0·02	
June 27 10 a. m.		Wat. Bot.	0·01	0·02
		82	0·02	
June 25	250	Wat. Bot.	0·48	0·49
		82	0·50	
		Wat. Bot.	0·47	0·49
		82	0·51	
June 26 5 p. m.		Wat. Bot.	0·15	0·16
		82	0·17	
June 27 10·10 a. m.		Wat. Bot.	0·29	0·30
		82	0·30	
June 25	275	Wat. Bot.	0·27	0·29
		82	0·31	
		Wat. Bot.	0·28	0·29
		82	0·31	
June 26 5·30 p. m.		Wat. Bot.	0·18	0·19
		82	0·20	
June 27 10·25 a. m.		Wat. Bot.	0·23	0·25
		82	0·26	

Date 1894	Depth in Metres	Instrument	Final Value of Temp. Read.	Mean of Simultan. Observat.
	m.		° C.	° C.
June 25 afternoon	300	Wat. Bot.	0·50	0·53
		82	0·55	
June 26 6 p. m.		Wat. Bot.	0·53	0·54
		82	0·55	
June 27 10 a. m.		Wat. Bot.	0·36	0·35
		82	0·33	
June 26 7·15 p. m.	310	Wat. Bot.	0·55	0·57
		82	0·58	
June 25 evening	325	Wat. Bot.	0·51	0·55
		82	0·58	
June 26 9·30 a. m.		Wat. Bot.	0·30	0·32
		82	0·33	
June 26 7·30 p. m.		Wat. Bot.	0·53	0·55
		82	0·56	
June 27 11 a. m.		Wat. Bot.	0·40	0·39
		82	0·38	
June 26 10 a. m.	350	Wat. Bot.	0·33	0·36
		82	0·38	
June 27 11·20 a. m.		Wat. Bot.	0·38	0·38
		82	0·37	
Aug. 13 5·30 p. m.	300	Wat. Bot.	0·18	0·18
Aug. 14 a. m.		Wat. Bot.	0·25	0·25
Aug. 13 5·45 p. m.	325	Wat. Bot.	0·33	0·33

Date 1894	Depth in Metres	Instrument.	Final Value of Temp. Read.	Mean of Simultan. Observat.
	m.		° C.	° C.
Aug. 13 6 p. m.	350	Wat. Bot.	0·29	0·29
Aug. 14		Wat. Bot.	0·28	0·28
		82	0·28	
1895 July 29	160	82	−0·79	−0·79
		80	−0·85	−0·85
	180	82	0·38	0·38
		80	−0·14	−0·14
	200	84	0·27	0·27
		80	0·31	0·31
		80	0·44	0·44
		82	0·68	0·68
	250	82	0·94	0·94
		80	1·13	1·13
	300	80	1·18	1·18
	350	84	1·19	1·19
		80	1·18	1·18
	400	84	0·99	0·99
		80	0·98	0·98
	500	84	0·72	0·72
		80	0·74	0·74
	600	84	0·55	0·55
		80	0·57	0·57

In the *third column* of the above table, *Wat. Bot.* means that the temperature has been taken with Pettersson's insulated water-bottle. The figures 80, 82, 84 mean that the temperatures have been taken with the Negretti and Zambra reversing thermometer Nos. 75680, 75682, 75684.

In the *fourth column*, the final values of the temperature readings are given, after having been corrected by the errors given in the Tables on pp. 240—242. When there is no line between the readings of the water-bottle and the reversing thermometer, it indicates that the two observations were

taken simultaneously in the same sounding, their mean being given in the *fifth column*. A line between two observations at the same depth indicates that they are taken in different soundings, often on different dates. In some cases the hour of the observation was recorded in the journal, and is given in the first column under the date; but as a rule this entry was unfortunately neglected.

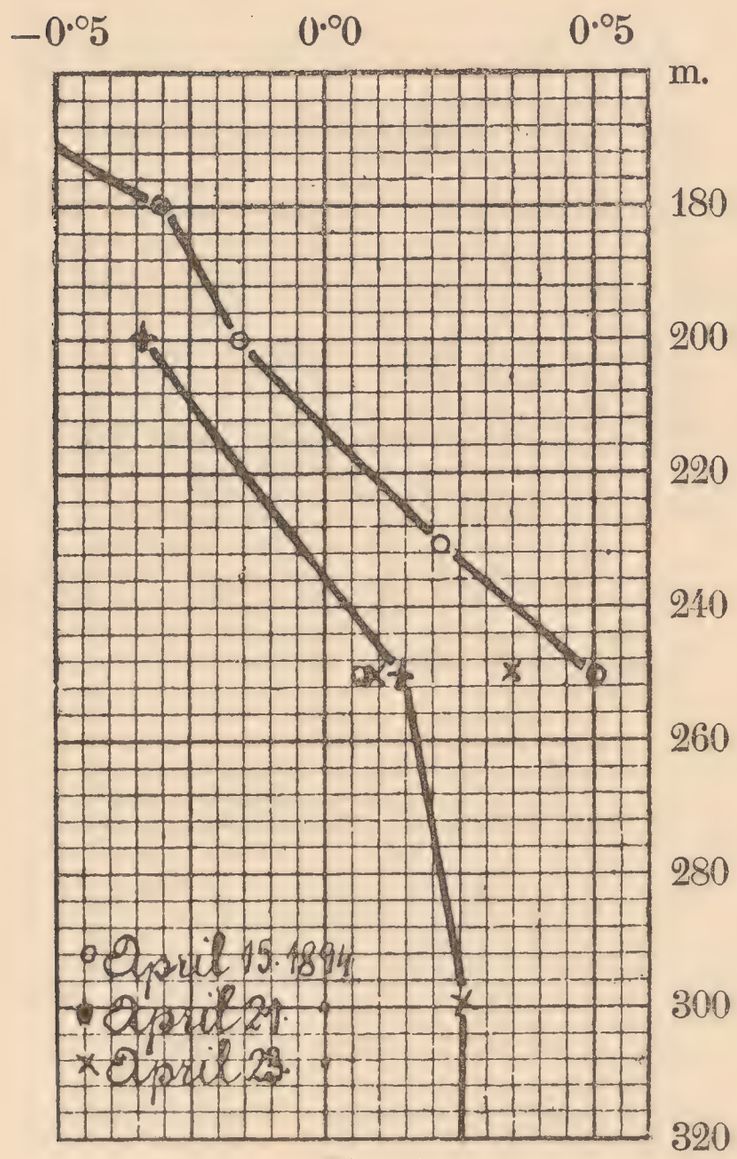

Fig. 1.

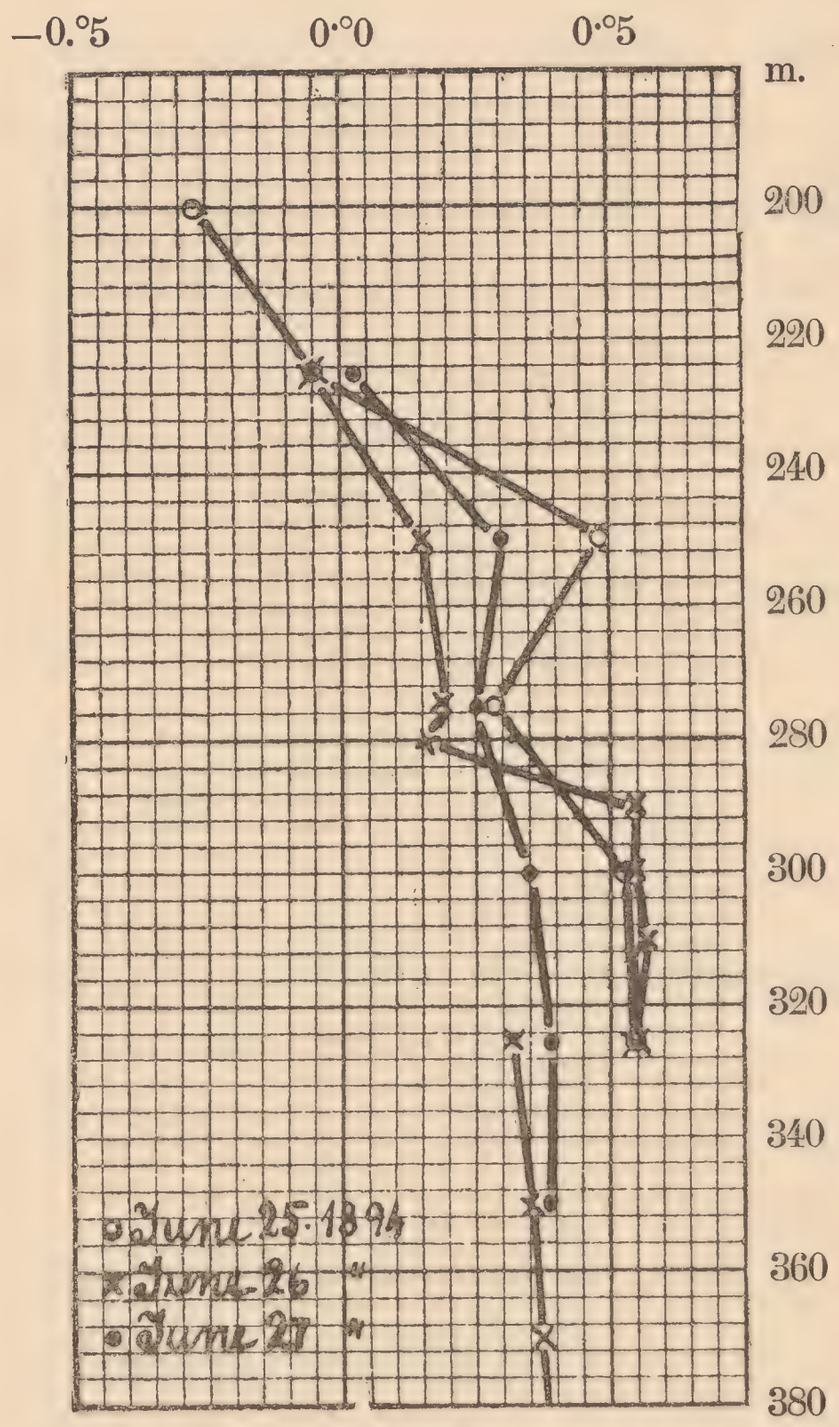

Fig. 2.

It will be seen that the readings taken simultaneously with Pettersson's insulated water-bottle and the reversing thermometers, give as a rule very nearly the same result; and the possibility of considerable errors seems thus to be excluded. The difference between the two kinds of simultaneous observations in some few cases, *e. g.* April 15th from 200 m., may also arise from the fact that the water-bottle did not give the temperature of exactly

the same stratum as the reversing thermometer. The observations of the specific gravity have not been taken sufficiently frequently to demonstrate these oscillations, except perhaps from April 15th to 23rd from 250 m. (see p. 168).

Our observations of the temperature show that water which at one time was found at a certain depth, at other times was found 20 m. or 30 m. or sometimes even 40 m. nearer the surface (cf. the curves of temperature, figs. 1, 2, p. 349). On some dates I even observed, especially at 250 m., such a high temperature as was never observed at any depth on subsequent dates.

On April 15th, 1894, I found at 250 m. 0·51° C. while the highest temperature observed at the same depth on the subsequent dates (April 21st and 23rd) was only 0·35° C., which was the highest temperature observed at any depth in the whole series on April 23rd. On June 25th, 1894, at 250 m. and 300—325 m., and on June 26th at from 290 to 325 m., I observed higher temperatures (about 0·55° C.) than were found at any depth in the whole series of observations on June 27th. How this sudden occurrence of comparatively very warm water at a certain depth on some dates is to be explained, seems to me doubtful.

During the cruise of the *Michael Sars* in the summer of 1900, I found in the sea between Iceland and Jan Mayen similar oscillations in the boundary between the cold, overlying, polar water and the underlying, heavier, Atlantic water. The oscillations were here even more marked, the differences in temperature at the same depth amounting to one or even two degrees Centigrade.

That we here had vertical currents between the two layers is hardly probable, as the density increases too rapidly with the depth. I thought at first that we possibly had waves at intermediate depths similar to those which the experiments of Prof. *V. Bjerknes* and Mr. *W. Ekman* on 'dead water' have proved to exist at boundary-lines between two water-strata of different density (see Ekman's memoir later). Such waves moving in a medium with a slightly lower density would naturally be capable of acquiring very large dimensions.

At my request, Mr. Ekman has made investigations in the Christiania Fjord to discover whether such waves do occur at intermediate depths, but with negative results. It may, however, be that this fjord is too enclosed to

allow of such waves being formed. Mr. Ekman simultaneously made investigations of the currents in the fjord, and found striking irregularities and changes in the deeper currents.[1] I consider it very probable that similar variations in the deeper currents may even exist in the open sea, especially where currents meet or run in different directions, overlying each other; and I consider it possible that the oscillations in the boundary between the cold polar water, and the underlying, warmer but heavier, Gulf Stream water, may be due to such apparently irregular currents or small vortices which may easily arise from the friction between overlying and underlying strata moving in different directions; but at the same time, waves may perhaps also be formed at the boundary in a manner similar to that which Helmholz has assumed to occur in the higher strata of the atmosphere.

The phenomenon seems to me to be of considerable interest, and certainly deserves further investigation.

d. *The Density of the Water of the North Polar Basin.*

The density ($S\frac{t}{4^\circ\,\mathrm{C.}}$) of the water of the North Polar Basin is given in the 8th column of the Table on pp. 245 *et seq.*, and in the Table on the next page. The figures in brackets in the latter Table are the means of the observations taken at the nearest depths above and below. Pl. XVI demonstrates the vertical distribution of the density in the North Polar Basin along the Fram's route.[2] We see that the course of the isopyknals (lines of equal density) in the section resemble more that of the isohalines than that of the isotherms; and we thus see that in this sea the salinity is of more importance for the density than the temperature, which varies comparatively little.

Although our method of determining the specific gravity of the sea-water was unfortunately not sufficiently accurate to demonstrate the details in the form of the isopyknals, there are certain undulations which are evidently not of an accidental nature. The isopyknals of 1·0275 and 1·0280, for instance, rise to some extent regularly at Stats. 19 and 23, and in such a

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[1] See *V. Walfrid Ekman,* ' On a new Current-Meter invented by Prof. Fridtjof Nansen'. Nyt Magazin for Naturvidenskab, vol. 39, Christiania, 1901, pp. 173 *et seq.*

[2] The horizontal scale of the section is reduced to the half of that of the sections on Pl. XIV and XV, the vertical scale being thus 2000 times too large in proportion.

TABLE OF DENSITY, $S\frac{t}{4^\circ C.}$

Depth in m.	1895			1894					Mean
	24 Nov. —Dec.	23 July	22 May	20 Nov.	19 October	16 June	15 May	14 April	
0		1·02532	1·02517	1·00376		1·00397	1·02407	1·02408	1·01773
5				2414	1·02394	2389	[2424]		2405
10			2508	2413		2383	2440		2436
20		2590	2601	[2418]		2399	2429	2385	2470
40		2683	2664	[2610]	[2600]	2596	2598	2511	2609
60		2713	2718	[2720]	[2712]	2710	2698	2677	2707
80		2740	2738	[2730]	[2726]	2729	2734	2715	2730
100		2755	2746	2763	[2741]	2773	2760	2743	2754
120		2761	[2756]		[2755]	2763	2768	2763	2761
140	[1·02763]	2762	[2768]		[2769]	2772	[2771]	2781	2769
160	[2779]	2787	[2779]		[2784]	2780	2773	[2777]	2780
180	[2785]	2786	[2783]		[2798]	2785	[2776]	2772	2784
200	2791	2796	2786	2809	2812	2799	2779	2781	2789
250	2800	2805	2802	[2806]	2803	2814	[2824]	2803	2807
300	[2802]	2805	2804	2803	2810	2808	2812	2806	2806
350	[2804]	2805	2810	2810	2814	2815	[2812]	[2811]	2810
400	[2806]	2805	2809	2803	2820	2812	2812	2815	2810
450	2808	[2809]	2809	[2806]	2824	2818	[2810]	[2815]	2812
500	[2808]	2813	2807	[2809]	2818	2820	2809	2815	2812
600	[2809]	2813	2814	2814	2808	2825	2809	2818	2814
700	[2810]	2814	2816	2805	2818	2815	2803	[2823]	2813
800	2811	2817	2823	[2809]	2819	2807	2817	2827	2816
900	2811	2806	2810	[2813]	[2819]	[2808]	2823	[2822]	2814
1000		2832	2815	2817	[2819]	2809	2815	2817	2818
1200		2824	2820		[2820]	2804	2827	2820	2819
1400		2822			[2820]	[2807]	2818	2823	2818
1600		2821			[2820]	2809	2818	2818	2817
1800					[2821]		2818	2822	2820
2000					[2822]		2816	2821	2820
2200					[2823]		2826	2816	2822
2400					[2824]			2829	2827
2600					[2824]				2824
2800					[2824]				2824
3000					2824				2824

manner that the deepest isopyknal ascends the most, *e. g.* between Stations 15 and 19, while the elevation of the lines gradually decreases upwards until the isopyknal of 1·0260 at depths of about 40 m. shows no similar undulation. At Stations 22 and 24 there are, on the other hand, great depressions in the isopyknals of 1·0280 and 1·0275.

This is the same phenomenon as that already observed in the isohalines. The explanation may be found in the situation of the stations. If we consider the map on Pl. I (see also Geelmuyden's charts, vol. II) we shall find that Stations 19, 20, and 23 are situated a good distance south of a line drawn along the main direction of the whole drift, while Station 24 is situated comparatively far north. It seems probable that on the whole we were carried to the north of the axis of the warm heavy undercurrent coming from the Atlantic. It is therefore probable that the farther we deviated towards the left during our drift (*e. g.* at Stats. 19, 20, 23) the nearer would the heavier water underlying the surface current, approach to the surface, while on the other hand we must expect to find the water at the same depth, about 200 m., less saline and with lower densities at our most northern stations, *e. g.* Stat. 24. It will thus be understood that as long as we have no more material than the incidental observations made along the crooked track of the Fram, it is impossible to calculate with any satisfactory degree of accuracy the forces producing the circulation of the North Polar Basin. As a general feature it is striking how the isopyknals rise, on the whole, considerably from the east (Stat. 9) towards the west (Stat. 23), especially in the strata between 0 m. and 200 m. There is consequently a comparatively strong tendency in the surface-water to be carried in this direction. This force of circulation may be easily calculated, according to the diagrammatic method described by Prof. *V. Bjerknes* and Mr. *J. W. Sandström,* the friction of the water not being considered.[1]

For this purpose the section of isosteres (lines of equal specific volume) on Pl. XVII has been constructed.[2] The acceleration, *g,* of the force of circu-

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[1] *V. Bjerknes* and *J. W. Sandström,* 'Über die Darstellung des hydrographischen Beobachtungsmateriales durch Schnitte, die als Grundlage der theoretischen Diskussion der Meerescirkulation und ihrer Ursachen dienen können'. Gothenburg, 1901.

[2] The section of the densities, Pl. XVI, may be used for the same purpose; only that the solenoids formed by the isopyknals and the isobars give *velocity* multiplied by *density,* i. e. *quantity of movement,* in a simple manner similar to that in which the

lation (not considering the friction of the water) has only been calculated for the upper 200 m., as our method of determination of the density was not accurate enough to give material for a calculation of the force in the deeper strata where the isopyknals or isosteres run fairly horizontally. The following calculations have been made:

(1) *Between Stat. 11 and Stat. 15* there are 14600 solenoids.

The distance is 48 100 000 cm., the depth 20 000 cm.

$$g = \frac{14\,600}{2 \times (48\,100\,000 + 20\,000)} = 0{\cdot}0001517 \text{ cm. per second.}$$

The velocity expressed in cm. per second would increase 13·107 cm. in 24 hours.

(2) *Between Stat. 15 and Stat. 23* there are 8650 solenoids.

Distance = 72 705 000 cm., depth = 20 000 cm.

$$g = \frac{8650}{2 \times (72\,705\,500 + 20\,000)} = 0{\cdot}00005947 \text{ cm. per second.}$$

This corresponds to an increase in the velocity of 5·138 cm. in 24 hours.

(3) *Between Stat. 23 and Arrhenius's Stat. IV*[1], west of Spitsbergen (in 79° N. Lat., 4° 45′ E. Long.), there are 12 500 solenoids.

Distance = 114 000 000 cm., depth = 20 000 cm.

$$g = \frac{12500}{2 \times (114\,000\,000 + 20\,000)} = 0{\cdot}0000548 \text{ cm. per second.}$$

This corresponds to an increase in the velocity of 4·736 cm. in 24 hours.

Another and easier manner to find the values of the accebration of the force of circulation at the sea-surface between two stations, which will give sufficiently accurate results for practical purposes, is naturally to calculate the mean density (q_1 and q_2) of the upper 200 metres of water at both stations (simply by taking the means of the densities for every 10 or 20 metres), and then the difference of height necessary to give the same pressure on the underlying water-strata at both places. Let g be the acceleration of the circulating force, G the acceleration of the gravitation, d the distance between the two stations, h the thicknes of the layer (in this case 200 m.), and

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solenoids of isosteres and isobars give velocity. In our section on Pl. XVII, the isobars are not drawn, as for these small depths the horizontal lines for every four metres give sufficient accuracy.

[1] Bihang till K. Svenska Vet.-Akad. Handlingar, vol. 23, No. 4, pag. 32.

$q_1 < q_2$. If we assume that the force of circulation has to produce a motion of the surface strata in its own direction, and also an equal motion of compensation of the underlying strata in the opposite direction; we have

$$g = \frac{h\left(\frac{q_2}{q_1} - 1\right) G}{2\,(d+h)}$$

Calculated in this manner we find the acceleration of the force of circulation at the sea surface,

between Stats. 11 and 15	= 0·0001898	between Stats. 11 and 23	= 0·0001154
„ „ 15 „ 23	= 0·0000675	„ „ 11 „ IV	= 0·0000820
„ „ 23 „ Arrh. IV	= 0·0000680	„ „ 14 „ IV	= 0·0000699

We see that the values thus obtained are somewhat greater than those found by the first method, which is more accurate. The agreement is, however, sufficient for our purpose.

These calculations show at any rate that between Stat. 11 and Stat. 15, the force ot circulation carrying the surface-water towards the North-west was 2·5 times as great as the force between Stat. 15 and Stat. 23. This is simply what might be expected, for between the former Stations we were nearer to the chief origin of the force, the Siberian rivers. But it might also have been expected that the force of circulation would have increased westward, when the Fram approached the open sea west of Spitsbergen. Our calculations nevertheless give a smaller force of circulation between Stat. 23 and Arrhenius's Stat. IV than farther east. But it is evident that if we had sufficient observations of the density of the water at some station farther west along the route of the Fram, *e. g.* St. 26, our calculation would have given a much greater force of circulation between this point and Arrhenius's station, for it is probable that the salinity of the upper water-strata between 0 m. and 200 m. is much the same in this part of the sea, as it was found to be farther east. Judging from the temperatures, it is not improbable that the surface-layer of cold but less saline polar water was even thicker at St. 26 than, for instance, at St. 23. At 200 m. the temperature was 0·20° C. at St. 26, while it was 0·43° at St. 23, and 0·78° at St. 22. If we look at the map, it seems also probable that the upper layer of polar water would be thicker at St. 26, as well as at Stats. 25 and 24, than at Stats. 23 and 22, because the former stations are evidently situated more to the north in the

cold surface-current. Let us, however, assume that the salinity of the upper 200 m. of water is no less at St. 26 than at St. 23. The distance between St. 26 and Arrhenius's St. IV is about 585 kilometres, consequently very nearly half the distance between St. 23 and St. IV. The force of circulation is consequently double, and the acceleration would be about 0·0001 cm. per second; or the velocity, in cm. per second, would have an increase of 9·4 cm. in 24 hours. This is relatively a considerable force that is constantly tending to carry the surface-water southward at St. 26; and we can clearly see the effect of this current in the drift of the ice, as compared with the direction of the wind (see later).

On the whole the force of circulation found in the upper strata of the North Polar Basin is comparatively considerable. In the Baltic, where the force of circulation may be expected to be comparatively great, Bjerknes and Sandstrøm (l. c., p. 12) have calculated its acceleration to be 0·000078 cm. per second, which would increase the velocity, expressed in cm. per second, 6·74 cm. in 24 hours, if the friction of the water be not considered. The force of circulation is consequently to some extent greater in the North Polar Basin than in the Baltic, and if we take the average of the former it will not be very different.

If, when I conceived the plan of the expedition, I had known what our observations have now taught us, that the North Polar Basin is covered by a layer, 200 m. or 250 m. thick, of water with a comparatively low density, I might have come to the following conclusion: This surface-water with low density must have a strong tendency to spread over the heavier water to the south; the most probable outlet will then be the opening between Spitsbergen and Greenland, and, from the effect of the Earth's rotation, the water will flow south along the Greenland East Coast. In course of time the surface-water of the North Polar Basin must consequently, notwithstanding the winds, be forced out along this route, and will carry the ice along with it.

The drift of the ice and the surface-current of the sea is, however, to some extent influenced by the winds. Our regular wind observations during three years in connection with our astronomical determinations, may enable us to find the relation between the influence of the wind and that of the force of circulation of the water upon the surface-drift in this sea.

V.

THE CURRENTS OF THE NORTH POLAR BASIN, AND THE INFLUENCE OF THE WIND UPON THE DRIFT OF THE NORTH POLAR ICE.

Plates XVIII—XXVIII exhibit graphically the winds during the drift of the Fram, from Sept. 28th, 1893, to July 27th, 1896. The velocity of the wind in metres per second has been introduced for every 4 hours as straight lines drawn in the wind's true direction.[1] A velocity of 2 m. per second is equal, on Pls. XIX—XXVIII, to one millimetre of the wind lines. The arrows marked with dotted lines indicate the direction of the meridian, and the figure at the end the degrees east of Greenwich. If the resultant of the wind between two certain dates be desired, the corresponding places of these dates has merely to be found on the drawings, and a straight line drawn between them. This line gives the direction and the relative magnitude of the resultant. If the length of the line be measured in millimetres, and their number be divided by half the number of watches (of 4 hours), the mean velocity, in metres per second, of the prevailing wind (the wind resultant) is immediately found. If the wind resultants be compared with the distance and direction of the drift of the Fram during the same period of time, it may be possible

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[1] I had a special instrument constructed for this purpose, according to Mr. *J. W. Sandströms* suggestion. It consisted of a ruler graduated in mm., fixed to another ruler at one end, and with the other end moveable along a graduated sector of a circle. The instrument could easily be moved parallel to itself over the drawing-board. By this instrument the work was much facilitated, and was made more accurate. I take the opportunity of expressing to Mr. *Sandström* my best thanks for his valuable assistance.

to find the influence of the wind upon the drift. In order to facilitate such a comparison, the wind resultants and the drift resultants have been drawn on the plates for a great many intervals.

Pl. XVIII demonstrates on a much reduced scale, the general relation between the winds and the movement of the ice during the whole drift-voyage of the Fram.

The first thing that strikes one in these plates is the apparent accordance between the changes in the direction of the winds and that of the drift, and it may give the impression that this force is of predominating importance as regards the movements of the ice. The chief resultant of the wind during the whole drift from November 8th, 1893, to June 28th, 1896,[1] has very nearly the same direction as the resultant of the drift during the same period, the latter deviating only a trifle (1°) towards the left (see Pl. XIX). It should, however, be remembered that the force of circulation of the water would have, as we have seen above, a comparatively strong tendency to carry the surface-water in much the same direction, *i. e.* from the sea to the north of Siberia towards the sea west of Spitsbergen, even if no winds had existed (cf. p. 356); and the deviation of the main resultant of the drift towards the left of the main resultant of the wind is, as we shall see presently, just a proof of the existence of this force.

a. *The Permanent Surface Current of the North Polar Basin.*

Let us first see whether our plates give indications of a permanent current in the surface of the sea, independent of the local winds. We might expect to find the effect and direction of such a current during long periods when the final resultant of the wind is zero. In the Table on p. 366, the drift resultant, etc., of these periods are given. The longest and most important of these periods are the following:

From *February 26th to April 17th, 1894,* (Pl. XX, XVIII) the wind-resultant is zero, but the ice was carried 26 nautical miles towards N 50°·5 W; *i. e.* **0·52 mile every 24 hours.**

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[1] After this date, the Fram began to force her own way southward through the ice, and thus her route is no longer exactly the same as that of the drifting ice.

From *May 4th to Sept. 1st, 1894,* the resultant of the wind is zero, but the resultant of the drift is about 54 naut. miles towards N 64° W *i. e.* **0·45 mile every 24 hours.**

From *May 27th to Oct. 30th, 1894,* the resultant of the wind is zero, and the resultant of the drift is 93 miles towards N 65° W; *i. e.* **0·60 miles every 24 hours.**

From *May 3rd to August 21st, 1895,* the resultant of the wind was zero, and the resultant of the drift 90 miles towards N. 92° W; *i. e.* **0·82 mile every 24 hours.**

From *February 2nd to March 21st, 1896,* the wind-resultant was zero, and the drift resultant was 49 miles towards S 25° W (N 155° W), *i. e.* **1·00 mile every 24 hours.**

From *April 20th to June 2nd, 1896,* the final wind-resultant was zero, and the drift-resultant was 42 naut. miles towards S 12° W, *i. e.* **1·00 mile every 24 hours.**

These facts give definite indications of a permanent current existing in the surface-layers of the sea.

For shorter periods with a wind resultant of zero, we might naturally expect more irregularity in the direction and the daily rate of the drift, produced by this current, as local and accidental influences may then be of more importance; but as may be seen in the Table on p. 366 there is a certain tendency towards regularity even during these periods.

Our observations seem to prove that the *daily rate of the permanent current* increases greatly towards the west. That this increase is fairly regular may be easily seen if the velocity of the drift produced by the current during the various months be introduced in a system of coördinates (see fig. 3) with the longitude of the observations along the ordinate, and the velocities of the current along the abscissa, the line drawn between the velocities introduced for the longer periods (marked by a circle on fig. 3) will then form a fairly regular curve.

The *direction* of this drift is very nearly the same along the whole route of the Fram. The true direction of the drift increases from about N 65° W in the summer of 1894, to about N. 168° W in the spring of 1896, but simultaneously the Longitude changed about 105°, namely, from about 125° E. (in 1894) to about 20° E. (in the spring of 1896); so that if the directions of

the drift be referred to the same longitude, there will not be much difference between their angles with the meridian. This is also easily seen if the true direction of the currents observed, in degrees west of north be introduced in a system of coördinates, with the longitude along the ordinate, and the degrees of the angle along the abscissa, (see fig. 4); the angles observed during longer periods (marked by circles on fig. 4) will then be situated very nearly in a straight line.

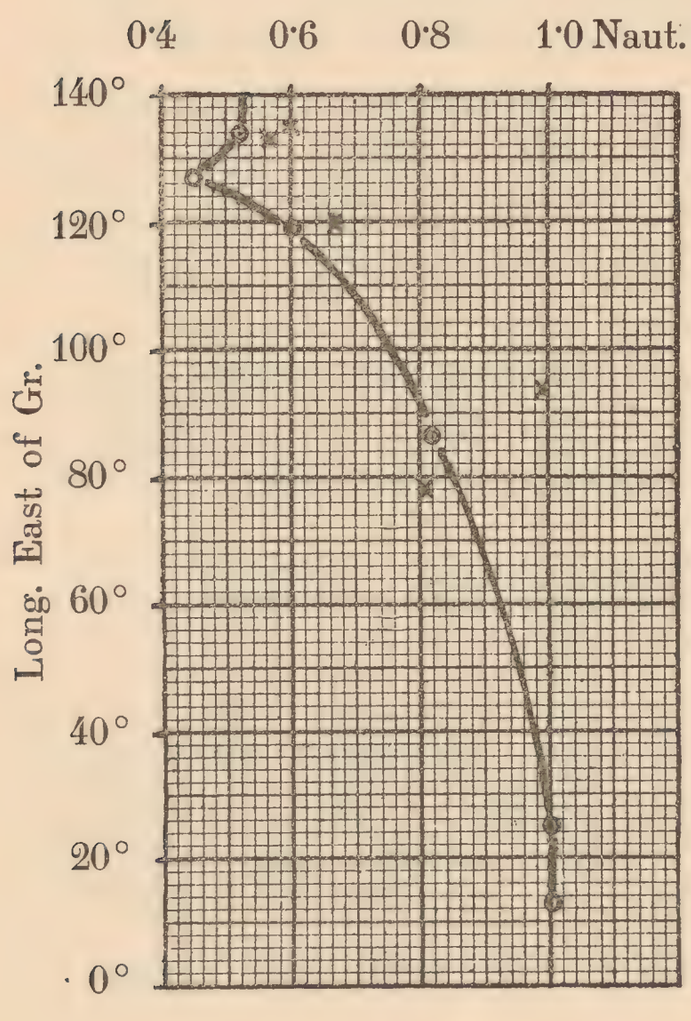

Fig. 3.

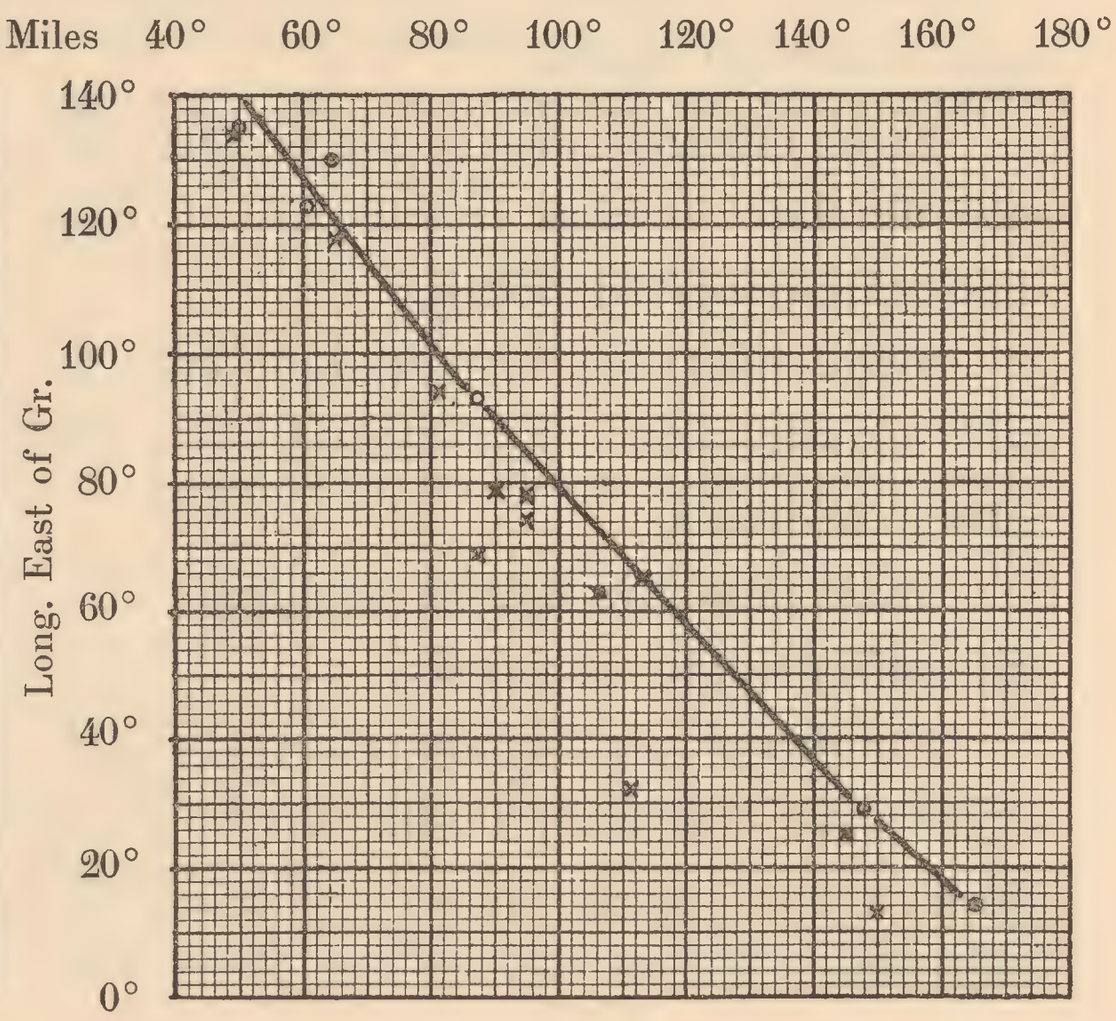

Fig. 4.

From these two diagrams it is easy to find the daily rate of the current and its direction for every month of the drift, if only the mean meridian of the month be known. This is done for the middle of every month in the Table on the next page.

Our method of determining the direction and velocity of the permanent surface current may involve the following chief sources of error: (1) It is not *a priori* certain that winds from all directions have an equal effect upon the ice-drift. The wind-effect will to some extent depend upon the resistance from other ice or from coasts, to which the drifting ice is exposed, and it is not certain that this resistance was the same in all directions. It is probable, for instance, that northerly winds had a relatively greater effect than other winds during the first part of the drift, as they blew towards a more open

Month	True Direction of Current	Rate of Current in Naut. Miles per 24 Hours	Month	True Direction of Current	Rate of Current in Naut. Miles per 24 Hours
15 Oct. 1893	N 54° W	0·53	15 March 1895	N 81° W	0·74
- Nov. —	- 52 -	0·53	- April —	- 85 -	0·76
- Dec. —	- 52 -	0·52	- May —	- 92 -	0·80
- Jan. 1894	- 53 -	0·52	- June —	- 99 -	0·85
- Febr. —	- 54 -	0·53	- July —	- 105 -	0·87
- March —	- 55 -	0·52	- Aug. —	- 101 -	0·86
- April —	- 56 -	0·51	- Sept. —	- 100 -	0·85
- May —	- 61 -	0·48	- Oct. —	- 104 -	0·87
- June —	- 64 -	0·54	- Nov. —	- 114 -	0·91
- July —	- 62 -	0·51	- Dec. —	- 125 -	0·95
- Aug. —	- 60 -	0·52	- Jan. 1896	- 139 -	0·98
- Sept. —	- 63 -	0·54	- Febr. —	- 150 -	0·99
- Oct. —	- 68 -	0·60	- March —	- 153 -	1·00
- Nov. —	- 73 -	0·66	- April —	- 161 -	1·00
- Dec. —	- 76 -	0·70	- May —	- 168 -	1·00
- Jan. 1895	- 79 -	0·72	- June —	- 167 -	1·00
- Febr. —	- 80 -	0·73	Mean,	N 91° W	0·73

sea, where the ice would give less resistance. For the same reason, northerly and north-easterly winds may also have had a relatively greater effect during the last year. The errors thus produced do not, however, seem to be of much importance.

(2) It is not *a priori* certain that the angle at which, owing to the Earth's rotation, the drift produced by the wind is deflected from the direction of the wind, is constant and independent of the velocity of the wind or the drift (see later). If this angle of deflection be variable, it is clear that even in a sea with no current, an ice-floe is not necessarily carried back to the same place after a period with a final wind resultant of zero. As, however, the mean velocities of the wind and the drift are on the whole much the same in the different directions, and as the irregularities thus caused in one direction may to a great extent check those occurring during drift in other directions, it is not probable, that the errors thus arising will ever be of much importance.[1]

[1] It is possible that the drift during periods with a wind resultant of zero was produced by winds prevailing at the time in other parts of the sea; but it is not probable that this has been the case to any appreciable extent in our observations during longer

Although we thus see that there certainly are sources of error, the great regularity of the values found for the direction and velocities of the permanent surface current seem to indicate that our observations give fairly correct results.

Is the permanent current produced entirely by the force of circulation of the water (calculated on p. 354) *or is it also to some extent an accumulated effect of the prevailing winds?*

It seems to be certain that the prevailing winds during the whole year have the power to produce a current that is permanent at a certain depth.[1] But we have at present too few data to enable us to calculate the velocity of a permanent current thus produced. We do not even know the resistance arising from the internal friction of the water. It seems certain, however, that in our case this current cannot be of much importance as compared with the current produced by the force of circulation. The direction of the permanent current produced by the wind would, owing to the Earth's rotation, deviate much to the right of the prevailing direction of the wind, and even more than the drift of the ice (see later), as it is situated deeper, and the direction of the motion in a water-layer will naturally deviate towards the right of that of the overlying layer from which it receives the impetus.

We nevertheless find that the current of the water deviates towards the left of the prevailing wind. During the first year (Nov. 23rd, 1893—Nov. 23rd, 1894) the direction of the prevailing wind was N 41° W, and the direction of the permanent current referred to the same meridian was N 48° W (Difference = 7°). For the second year we find in a similar manner N 19° W and N 69° W (Difference 50°), and for the third year N 91° W and N 115° W (Difference = 24°).

The direction of the wind resultant of the whole drift of the Fram was N 19° W if referred to the meridian of November 7th, 1893. The direction

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periods, for we could not expect that the drift thus produced, would show any regularity. The striking regularity as to direction and rate, shown by our observations, indicates that we here have the effect of more or less stationary forces.

[1] Cf. Zöppritz's discussion of this point 'Annalen der Phys. und Chemie' vol. III, 1878, p. 582. Zöppritz has, however, made a mistake by not taking into consideration the deflecting force arising from the Earth's rotation. Owing to this force, the motion produced by the wind will deviate towards the right of the wind direction, and the angle of deviation will increase with the depth until at a certain depth, it is 90°, and at twice that depth 180°. In this manner the wind's power to produce currents is limited, and the effect cannot possibly reach the greatest depths, as stated by Zöppritz, except at the Equator (see later).

of the resultant of the ice-drift effected by this wind resultant would be N 18·5° E, if the drift due to the current be eliminated. The mean direction of the permanent current referred to the same meridian (of Nov. 7th, 1893) was N 45·5° W; it consequently deviated about 64° from that of the wind drift of the ice. The possible permanent current in the upper strata of the sea, produced by the wind drift of the overlying ice, would, however, be more easterly than the latter and it would thus at any rate form a considerable angle with the permanent current observed. Its velocity would, however, be relatively insignificant. The mean rate of the drift produced by the winds was about 0·52 mile in 24 hours; and the velocity of the permanent current produced by this irregular drift could only be a fraction of this rate. The mean velocity of the permanent current observed was, however, 0·73 mile in 24 hours. We see that we cannot make any considerable error by assuming that the permanent current observed was entirely due to the force of circulation of the water.

That the permanent current observed was only to a very small extent influenced by the prevailing wind, also appears probable from the fact that the current seemed to increase quite regularly towards the west, whether it was summer with long periods of contrary wind, or winter with more regular winds in the prevailing direction.

The current produced by the force of circulation of the water will naturally, in high latitudes, have a tendency to be deflected nearly 90° towards the right, owing to the Earth's rotation. But this deflection is generally much checked by the coasts, and especially in the enclosed North Polar Sea where the surface current is more or less compelled to flow towards the natural outlet between Spitsbergen and Greenland. We do not know the direction of the maximum force of circulation in the North Polar Basin, as we know only the densities of the sea-water along the route of the Fram. It seems probable that the direction of the maximum force is towards the Barents Sea and the northern Norwegian Sea where the density of the upper water-strata is relatively considerable.

The rate of the current increases towards the west, from 0·45 mile daily in the summer of 1894, to 1·0 mile daily in February and May, 1896. It is natural that the velocity must increase towards the opening between Spitsbergen and Greenland which forms a comparatively narrow outlet for the

surface water from the wide and extensive Basin. The increase of the rate may perhaps to some extent also be due to the circumstance that we were carried by the winds in a direction which, especially during the second year, differed much from that of the cold surface-current, and during the latter part of the drift we had evidently come nearer to its axis, where the rate of the current was greater. This would also explain why the current did not increase during the last months, for then the Fram travelled nearly in the direction of the current. On the other hand we have also seen above (p. 356) that the force of circulation was probably greater north of Spitsbergen than farther east. According to our observations it seemed, however, to be greatest near the New Siberian Islands. The explanation of this apparent difference may to some extent be that the direction of the section was there more similar to that of the maximum force of the circulation: but nevertheless the force was probably greatest in this region, and the reason why the drift due to the current was not more visible there may be, not only the accumulating effect of the force, but also the different effect of the different winds. We have seen above that northerly winds had probably a comparatively great effect upon the ice-drift both during the first part (cf. the drift during October, 1893) and the last part of the Fram's drift-voyage. It is thus possible that our observations will give somewhat too low values of the rate of the permanent current during the first part of the drift and too high values during its latter part; but the inaccuracy is hardly of much importance, and the mean value for the whole drift will nevertheless be nearly correct.

There seems to be one irregularity in this respect during the first winter, when the observed rate of the current was higher than that of the subsequent summer. This may, however, chiefly be due to the circumstance just mentioned that the force of circulation actually was very great in that region (see Pls. XVI, XVII) owing to the river water from the Siberian coast. It may to some extent also be due to the fact that during this winter the wind-drift formed a relatively small angle with the current, and thus the latter may have been somewhat increased by the permanent current produced by the wind.

b. *The Influence of the Wind upon the Ice-Drift.*

The following Table will show the particulars of the relation between the wind and the drift during the different periods.

The columns give:

First column, the Dates of the Periods.

Second column, the Wind Resultant in Millimetres as measured on the Plates. 1 mm. = a wind velocity of 2 m. per second.

Third column, Drift Resultant in Nautical Miles.

Fourth column, True Direction of Wind Resultant.

Fifth column, True Direction of Drift Resultant.

Sixth column, Angle in Degrees between the two Resultants, + before the figure indicates that the Drift Resultant is deflected towards the right of the Wind Resultant, and — before the figure indicates that the Deflection is towards the left.

Seventh column, the Mean Velocity of the Prevailing Wind (Wind Resultant) in Metres per Second.

Eighth column, the Mean Velocity in 24 Hours of the Prevailing Drift (Drift Resultant) expressed in Nautical Miles.

Ninth column, the Angle in Degrees between the Drift Resultant and the Current.

Tenth column, the Velocity of the permanent Current in Nautical Miles per 24 Hours.

Eleventh column, the mean Rate in 24 Hours of the Drift produced by the Wind, the effect of the Current having been eliminated.

Twelfth column, the Wind Drift produced by a Wind with a Velocity of 1 m. per second, the effect of the current having been eliminated.

Thirteenth column, the Angle in Degrees between the Resultant of the Wind-Drift (the effect of the current being eliminated) and that of the Wind; + indicates that the Deviation of the Drift is toward the right of the Wind, and — that it is towards the left.

Dates of Periods	Wind Resultant in mm.	Drift-Resultant in naut. Miles	Direction of Wind Resultant	Direction of Drift Resultant	Angle between the two Resultants	Mean Velocity of Wind in m. per Second	Mean daily Drift in naut. Miles	Angle between Current and Drift Resultant	Daily Rate of Current in naut. Miles	Mean daily Drift due to Wind in naut. Miles	Daily Wind Drift produced by a Wind Velocity of 1 m. per Second	Angle between Wind Drift and Wind Resultant
Oct. 13, 1893 — Oct. 23, 1893	0	6	—	N 53° W	—	—	0·60					
Dec. 19 „ — Dec. 29 „	0	9·4	—	- 163 -	—	—	0·94					
Febr. 4, 1894 — Febr. 20, 1894	0	8·6	—	- 49 -	—	—	0·57					
Febr. 26 „ — Apr. 17 „	**0**	**26**	—	**- 50 -**	—	—	**0·52**					
March 4 „ — Apr. 12 „	0	19	—	- 21 -	—	—	0·50					
May 4 „ — Sept. 1 „	**0**	**54**	—	**- 64·5 -**	—	—	**0·45**					
May 29 „ — June 22 „	0	14	—	- 35 -	—	—	0·58					
May 27 „ — Oct. 30 „	**0**	**93**	—	**- 60·5 -**	—	—	**0·60**					
July 1 „ — Oct. 21 „	0	75	—	- 65·5 -	—	—	0·67					
Nov. 1 „ — Nov. 24 „	0	8	—	- 176 -	—	—	0·35					
Febr. 4, 1895 — Febr. 20, 1895	0	2	—	- 173 -	—	—	0·12					
Apr. 7 „ — Apr. 17 „	0	5·6	—	- 107 -	—	—	0·53					
Apr. 24 „ — May 1 „	0	6·6	—	- 81 -	—	—	0·99					
May 3 „ — Aug. 21 „	**0**	**90**	—	**- 87 -**	—	—	**0·82**					
May 27 „ — July 27 „	0	49	—	- 95 -	—	—	0·80					
Sept. 7 „ — Sept. 11 „	0	5·4	—	- 15 -	—	—	1·25					
Sept. 29 „ — Oct. 5 „	0	4·2	—	- 90 -	—	—	0·65					
Oct. 23 „ — Oct. 28 „	0	5·6	—	- 95 -	—	—	1·24					
Oct. 31 „ — Nov. 4 „	0	6	—	- 87 -	—	—	1·33					
Nov. 7 „ — Nov. 27 „	0	28	—	- 106 -	—	—	1·40					
Nov. 13 „ — Nov. 20 „	0	11	—	- 113 -	—	—	1·54					
Jan. 26, 1896 — Jan. 30, 1896	0	7·2	—	- 111 -	—	—	1·80					
Febr. 2 „ — March 21 „	**0**	**49**	—	**- 148 -**	—	—	**1·00**					
Febr. 26 „ — March 12 „	0	18	—	- 145 -	—	—	1·29					
Apr. 20 „ — June 2 „	**0**	**42**	—	**- 165·5 -**	—	—	**1·00**					
Apr. 24 „ — May 9 „	0	18	—	- 150 -	—	—	1·16					
May 23 „ — May 30 „	0	8	—	- 166 -	—	—	1·20					
June 5 „ — June 17 „	0	16·6	—	- 147 -	—	—	1·38					
The whole drift												
Nov. 7, 1893 — June 27, 1896	2187	1028	N 19° W	- 20 -	— 1°	0·757	1·07	+25·°5	0·73	0·52	0·69	+37·°5
First year												
Nov. 23, 1893 — Nov. 23, 1894	832	342	- 41 -	- 40 -	+ 1	0·760	0·94	+8	0·54	0·41	0·54	+12
Second year												
Nov. 23, 1894 — Nov. 23, 1895	980	364	- 19 -	- 31 -	—12	0·895	1.00	+38	0·784	0·61	0·68	+40
Third year												
Nov. 23, 1894 — June 27, 1896	383	326·5	- 91 -	- 93 -	— 2	0·588	1·50	+22	0·979	0·70	1·19	+31
First winter												
Oct. 1, 1893 — June 1, 1894	674	192	- 36 -	- 31 -	+ 5	0·925	0·79	+23	0·52	0·37	0·404	+38
Second winter												
Oct. 1, 1894 — June 1, 1895	1177	342	- 39 -	- 35 -	+ 4	1·62	1·41	+26	0·71	0·84	0·521	+26
Third winter												
Oct. 1, 1895 — June 1, 1896	519	378	- 63 -	- 69 -	— 6	0·709	1·55	+30	0·96	0·87	1·23	+28

Dates of Periods	Wind Resultant in mm.	Drift-Resultant in naut. Miles	Direction of Wind Resultant	Direction of Drift Resultant	Angle between the two Resultants	Mean Velocity of Wind in m. per Second	Mean daily Drift in naut. Miles	Angle between Current and Drift Resultant	Daily Rate of Current in naut. Miles	Mean daily Drift due to Wind in naut. Miles	Daily Wind Drift produced by a Wind Velocity of 1 m. per Second	Angle between Wind Drift and Wind Resultant
[Sept. 29, 1893 — Jan. 9, 94]	225	64	N 45° E	N 82° E	+37°	0·74	0·63	+141°	0·53	[1·09]	[1·47]	[+ 54°]
[Sept. 29 „ — Nov. 3, 93]	252·5	70	- 126 -	- 145 -	+19	2·41	2·00	+201	0·53	[2·50]	[1·04]	[+ 16]
Sept. 29 „ — Oct. 5 „	92	56	- 84 -	- 105 -	+21	5·11	9·33	+158	0·53	9·80	1·92	+ 22
Oct. 5 „ — Oct. 12 „	118	22	- 142 -	- 177 W	+41	5·62	3·14	−124	0·53	3·46	0·61	+ 34
Oct. 12 „ — Oct. 26 „	22·5	19	- 68 -	- 7 E	−61	0·54	1·36	+ 61	0·53	1·19	2·20	− 38
Oct. 26 „ — Nov. 1 „	67	34	- 173 -	- 150 W	+37	4·46	6·80	− 97	0·53	6·90	1·55	+ 32
Nov. 1 „ — Nov. 7 „	84·5	41	- 74 -	- 101 E	+27	4·68	6·83	+153	0·53	7·30	1·56	+ 29
[Nov. 7 „ — Jan. 16, 94]	353·5	86	- 18 W	- 4 W	+14	1·71	1·25	+ 48	0·52	[0·98]	[0.57]	[+ 37]
Nov. 7 „ — Nov. 23, 1893	114·5	45	- 5 -	- 24 E	+29	2·39	2·81	+ 76	0·53	2·73	1·14	+ 40
Nov. 23 „ — Dec. 12 „	160	44	- 30 -	- 30 W	0	2·81	2·32	+ 21	0·52	1·85	0·66	+ 6
Dec. 12 „ — Dec. 31 „	37	14	- 108 -	- 134 -	−26	0·65	0·74	− 83	0·52	0·85	1·31	− 63
Dec. 31 „ — Jan. 15, 1894	100	19·6	- 12 E	- 24 E	+12	2·08	1·23	+ 77	0·52	1·22	0·59	+ 36
Jan. 15, 1894 — Feb. 22 „	202	66	- 25 W	- 35 W	−10	1·78	1·74	+ 18	0·53	1·25	0·70	− 2
Feb. 22 „ — March 19 „	193	34	- 125 E	- 152 E	+27	2·57	1·36	+206	0·52	1·84	0·72	+ 20
March 19 „ — Apr. 9 „	143	37	- 20 W	- 6 W	+14	2·27	1·76	+ 48	0·52	1·47	0·65	+ 30
Apr. 9 „ — Apr. 21 „	129	38	- 89 -	- 69 -	+20	3·58	3·17	− 14	0·51	2·68	0·75	+ 23
Apr. 21 „ — Juue 25 „	410	118	- 72 -	- 47 -	+25	2·11	1·82	+ 8	0·51	1·23	0·58	+ 29
June 25 „ — Aug. 17 „	341	73	- 77 E	- 112 E	+35	2·14	1·38	+ 1	0·52	1·89	0·88	+ 35
Aug. 17 „ — Sept. 13 „	121	65·2	- 138 W	- 79 W	+59	1·49	2·41	− 15	0·54	1·89	1·27	+ 55
Sept. 13 „ — Sept. 16 „	36	32	- 4 E	- 82 E	+78	4·00	10·67	+146	0·54	11·14	2·79	+ 80
Sept. 16 „ — Oct. 1 „	93	26	- 153 -	- 120 W	+87	2·07	1·73	− 54	0·57	1·47	0·71	+ 68
Oct. 1 „ — Nov. 13 „	391	120	- 76 W	- 55 -	+21	3·03	2·79	+ 11	0·63	2·19	0·72	+ 24
Nov. 13 „ — Nov. 24 „	79	18	- 95 E	- 122 E	+27	2·39	1·64	+195	0·66	2·28	0·95	+ 22
Nov. 24 „ — Dec. 25 „	405	114	- 52 W	- 39 W	+13	4·35	3·68	+ 31	0·70	3·16	0·73	+ 20
Dec. 25, 1894 — Jan. 12, 1895	153	19	- 10 E	- 20 E	+10	2·83	1·06	+ 98	0·71	1·36	0·57	+ 42
Jan. 12, 1895 — Jan. 21 „	74	19·2	- 139 -	- 170 W	+51	2·74	2·13	− 91	0·72	2·26	0·82	+ 33
Jan. 21 „ — Feb. 2 „	91	21.4	- 1 W	- 15 E	+16	2·53	1·78	+ 94	0·72	1·95	0·77	+ 37
Feb. 2 „ — Feb, 12 „	59	19	- 110 E	- 171 -	+61	1·97	1·90	+251	0·73	2·25	1·14	+ 34
Feb. 12 „ — March 4 „	159	43·4	- 44 W	- 23 W	+21	2·65	2·17	+ 57	0·73	1·88	0·71	+ 39
March 4 „ — March 9 „	56	8·4	- 74 E	- 137 E	+63	3·73	1·68	+218	0·74	2·31	0·62	+ 52
March 9 „ — May 1 „	248	58	- 72 W	- 72 W	0	1·56	1·09	+ 7	0·76	0·34	0·22	+ 16
May 1 „ — May 27 „	214	70	- 79 -	- 66 -	+13	2·74	2·69	+ 22	0·80	1·98	0·72	+ 22
May 27 „ — June 7 „	79	15	- 76 E	- 106 E	+30	2·39	1·36	+201	0·83	2·15	0·90	+ 22
June 7 „ — June 16 „	121	34	- 67 W	- 54 W	+13	4·48	3·78	+ 45	0·85	3·23	0·72	+ 23
June 16 „ — June 24 „	106	22·8	- 126 E	- 166 E	+40	4·42	2·85	+265	0·85	3·04	0·69	+ 24
June 24 „ — July 3 „	123	35	- 102 W	- 56 W	+46	4·55	3·89	+ 45	0·86	3·34	0·73	+ 56
July 3 „ — July 5 „	32	8	- 8 E	- 73 E	+65	5·33	4·00	+174	0·86	4·85	0·91	+ 66
July 5 „ — July 7 „	17	8	- 47 W	- 57 W	−10	2·83	4·00	+ 44	0·86	3·44	1·21	0
July 7 „ — July 11 „	51	11·2	- 52 E	- 130 E	+78	4·25	2·80	+231	0·86	3·32	0·78	+ 67
[July 3 „ — July 11 „]	85	8	- 24 -	- 91 -	+67	3·54	1·00	+192	0·86	[1·85]	[0·52]	[+ 62]
July 11 „ — July 24 „	69·5	25·6	- 177 W	- 111 W	+66	1·78	1·97	− 8	0·87	1·12	0·63	+ 59
July 24 „ — Aug. 2 „	140	33·6	- 48 E	- 89 E	+41	5·18	3·73	+190	0·86	4·57	0·88	+ 39
Aug. 2 „ — Aug. 5 „	29	7·6	- 9 W	- 9 W	0	3·22	2·53	+ 91	0·86	2·69	0·84	+ 18
Aug. 5 „ — Aug. 17 „	103	17·4	- 130 E	- 140 -	+90	2·86	1·45	− 40	0·86	0·96	0·34	+ 55
Aug. 17 „ — Aug. 22 „	104.5	27·4	- 69 -	- 123 E	+54	6·97	5·48	+223	0·86	6·10	0·87	+ 48
[Aug. 5 „ — Aug. 22 „]	181	30	- 101 -	- 161 -	+60	3·55	1·76	+261	0·86	[2·03]	[0·57]	[+ 35]

Dates of Periods	Wind Resultant in mm.	Drift-Resultant in naut. Miles	Direction of Wind Resultant	Direction of Drift Resultant	Angle between the two Resultants	Mean Velocity of Wind in m. per Second	Mean daily Drift in naut. Miles	Angle between Current and Drift Resultant	Daily Rate of Current in naut. Miles	Mean daily Drift due to Wind in naut. Miles	Daily Wind Drift produced by a Wind Velocity of 1 m. per Second	Angle between Wind Drift and Wind Resultant
Aug. 22, 1895 — Sept. 2, 1895	111·5	40	N 50° W	N 18° W	+ 32°	3·38	3·64	+ 81°	0·86	3·62	0·07	+ 47°
Sept. 2 „ — Sept. 22 „	111	26	- 47 E	- 41 E	— 6	1·85	1·30	+140	0·86	2·03	1·10	+ 9
Sept. 22 „ — Oct. 7 „	46	7·6	- 92 -	- 99 W	—191	1·02	0·47	+ 2	0·86	0·39	0·38	— 16
[Sept. 2 „ — Oct. 7 „]	149·5	20	- 58 -	- 25 E	— 33	1·42	0·57	+124	0·85	[1·26]	[0·89]	[+ 1]
Oct. 7 „ — Oct. 19 „	159	38·4	- 22 W	- 4 W	+ 18	4·41	3·20	+ 99	0·87	3·44	0·78	+ 33
Oct. 19 „ — Nov. 9 „	134	60·6	- 120 -	- 86 -	+ 34	2·18	2·88	+ 22	0·89	2·09	0·96	+ 43
Nov. 9 „ — Nov. 14 „	87	18	- 9 E	- 35 E	+ 26	5·80	3·60	+148	0·90	4·38	0·76	+ 32
Nov. 14 „ — Nov. 28 „	116	43	- 179 W	- 127 W	+ 52	2·76	3·07	— 13	0·91	2·19	0·79	+ 47
Nov. 28 „ — Dec. 15 „	137	52	- 98 -	- 89 -	+ 9	2·69	2·96	+ 33	0·94	2·23	0·83	+ 23
Dec. 15 „ — Dec. 21 „	56	10	- 142 -	- 164 -	— 22	3·11	1·67	— 39	0·95	1·11	0·36	— 55
Dec. 21 „ — Dec. 28 „	58	9·8	- 18 -	- 4 -	+ 14	2·76	1·40	+126	0·96	2·11	0·76	+ 36
Dec. 28, 1895 — Jan. 15, 1896	175·5	48	- 172 -	- 131 -	+ 41	3·25	2·66	— 4	0·97	1·69	0·52	+ 39
Jan. 15, 1896 — Jan. 21 „	66	14	- 46 -	- 58 -	— 12	3·66	2·33	+ 82	0·98	2·40	0·66	+ 12
Jan. 21 „ — Jan. 25 „	61	27	- 112 -	- 92 -	+ 20	5·08	6·75	+ 48	0·98	6·13	1·21	+ 26
Jan. 25 „ — Jan. 27 „	56	20	- 178 -	- 117 -	+ 61	9·33	10·00	+ 28	0·98	9·10	0·98	+ 64
Jan. 27 „ — Jan. 31 „	54	12·4	- 27 -	- 26 -	+ 1	4·50	3·10	+119	0·98	3·68	0·82	+ 14
Jan. 31 „ — Feb. 3 „	72	27·8	- 103 -	- 97 -	+ 6	8·00	9·27	+ 50	0·99	8·70	1·09	+ 11
Feb. 3 „ — Feb. 18 „	110	19·2	- 173 E	- 157 -	+ 30	2·44	2·61	— 5	0·99	1·73	0·71	+ 27
Feb. 18 „ — Feb. 29 „	107·2	22·4	- 35 -	- 100 E	+ 65	3·25	2·04	—107	0·99	2·51	0·77	+ 42
Feb. 59 „ — March 12 „	52	23·6	- 121 W	- 111 W	+ 10	1·44	1·97	+ 43	1·00	1·38	0·96	+ 39
March 12 „ — March 18 „	68	15·4	- 20 E	- 61 E	+ 41	3·78	2·56	+216	1·00	3·42	0·90	+ 31
March 18 „ — Apr. 4 „	184	24·4	- 12 W	- 29 W	— 17	3·61	1·44	+130	1·00	2·22	0·62	+ 3
Apr. 4 „ — Apr. 11 „	98	33	- 121 -	- 93 -	+ 28	4·67	4·71	+ 68	1·00	4·40	0·94	+ 40
Apr. 11 „ — Apr. 13 „	32	10·8	- 158 E	- 168 -	+ 34	5·33	5·40	— 4	1·00	4·40	0·83	+ 33
Apr. 13 „ — Apr. 20 „	49	20	- 130 W	- 121 -	+ 9	2·33	2·86	+ 43	1·00	2·24	0·96	+ 27
Apr. 20 „ — Apr. 27 „	86·5	19	- 34 -	- 29 -	+ 5	4·12	2·71	+ 35	1·00	1·98	0·48	+ 22
Apr. 27 „ — May 19 „	61·5	30	- 167 E	- 178 E	+ 11	0·93	1·36	— 14	1·00	0·46	0·49	— 22
May 19 „ — May 24 „	77	16·4	- 12 -	- 40 -	+ 28	5·13	3·28	+209	1·00	4·18	0·81	+ 22
May 24 „ — June 18 „	124·5	66	- 146 -	- 173 W	+ 41	1·66	2·64	— 5	1·00	1·65	0·99	+ 38
June 18 „ — June 27 „	64	9	- 15 -	- 95 E	+ 80	2·37	1·00	+263	1·00	1·50	0·63	+ 38
									Mean,	2·98	0·85	+ 28°

c. *The Deviation of the Wind Drift caused by the Deflecting Force arising from the Earth's Rotation.*

Plates XVIII—XXVIII, as well as the above Table, demonstrate clearly that for shorter periods *the resultants of the drift deviate,* with some few exceptions, *towards the right of the corresponding wind-resultant,* and generally the deviation is *considerable.* This deviation cannot be explained as being the effect of the current in the water, or of the resistance of land, for it occurs in whatever direction the wind blows (cf. Sept. to Nov., 1893, Febr. 23 to March 20, 1895, June 25 to Aug. 17, 1895, etc.). If the drift due to the current be eliminated, we shall find that the wind drift, especially for longer periods, deviates without exception considerably towards the right of the wind-resultant (see the last column of the Table, especially for the whole drift, and for the different years).

This deviation towards the right is clearly due to the deflecting force arising from the Earth's rotation. Strange to say, extremely few authors seem to have sufficiently noticed the fact that a surface-current produced by a wind cannot follow the direction of the wind, but must be deflected towards the right; and they have therefore arrived at erroneous results when discussing the effect of the winds upon the surface.[1]

Still less has sufficient attention been paid to the fact that a surface-current produced by the wind will not be able to carry the underlying water along in its own direction, but the water will have a tendency to be deflected towards the right, and thus the angle of deflection of the water-strata will have a tendency to increase downward.

Taking into consideration what has been said above, Mr. *V. Walfrid Ekman* has kindly assisted me in the following calculations.

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[1] It has been said by Krümmel (cf. Boguslawski and Krümmel, Handbuch der Oceanographie, vol. II, p. 363) and others when discussing free currents in the Ocean, that the rate of the oceanic currents is so small, that the deflection due to the Earth's rotation will be of little importance; but it is naturally the reverse: *the deviation of a free current after having travelled a certain distance, will be in an inverse ratio to its velocity, i. e.* the longer the time that a free current requires to travel a certain distance, the greater will be its deviation towards the right. This is clear from the following formula:

$$d = \frac{a^2}{v} \cdot \omega \cdot \sin \beta$$

where d is the deflection in m., a the distance travelled, v the velocity in m. per second, ω the angular velocity of the Earth, and β the latitude.

It is assumed that the motion is stationary, that the water moves in horizontal tracks solely acted upon by the *Earth's rotation* and the *friction* (*i. e.* the *internal friction of the water* and the *tangential pressure of the wind against the water-surface*). It is assumed that the water-surface is not stirred by wave-formation (which will tend to increase its angle of deflection α), that the motion of the water is not hindered by coasts, or by the water in other regions being at rest or acted upon by different winds; it is further assumed that the velocity of the motion of the water is zero at great depths, and that the latitude and the direction of the wind may be considered as constant in the area in question. We have then

$$\begin{cases} u = \quad Ce^{-az}\cos az \\ v = -Ce^{-az}\sin az \\ \left(a = \sqrt{\frac{q\,\omega\,\sin\beta}{K}}\right) \end{cases}$$

where
- u = the component of the velocity of a water-particle along the x-axis
- v = the —„— —„— —„— y-axis
- z = the depth of a water-particle below the sea-surface
- q = the density of the water $\left(S\,\frac{t}{4^\circ\,\mathrm{C.}}\right)$
- K = the coefficient of the internal friction of the water (= 0·018[1] for distilled water at 0° in units of *c. g. s.*)
- ω = the angular velocity of the Earth
- β = the geographical latitude
- C = the velocity of the motion at the sea-surface (which increases with the wind-velocity).

The z-axis is directed vertically downwards, and the x-axis and the y-axis are directed horizontally, the y-axis 90° towards the left of the x-axis. Further, the formula is so arranged that the x-axis has the same direction as the current on the sea-surface.

According to this formula, the arrows indicating the direction and velocities of the current at the different depths will form, as it were, a spiral staircase, the breadth of which decreases regularly downwards. If the arrows be projected on the same horizontal plane, we find that the tangent to the curve drawn through the points of these arrows, must everywhere form an

[1] This value of K is evidently much too small for oceanic currents (see later).

angle of 45° with the corresponding arrow. If the water-particles of a certain stratum travel during a certain interval from A to B' (fig. 5), and the water-particles of another underlying stratum travel during the same interval from A to C', it is clear that the water-particle at B' must have been exposed, from above, to a force acting in the direction of $C'B'$, for otherwise the water-particles of the stratum AB' would be carried by the underlying water-stratum in the same direction and the same distance as AC'[1]; in other words, in order to reach B', the particles of the overlying stratum must glide on the underlying stratum from C' to B'. Or we might also say that the particles at C' must have been exposed, from below, to a force directed from B' to C',

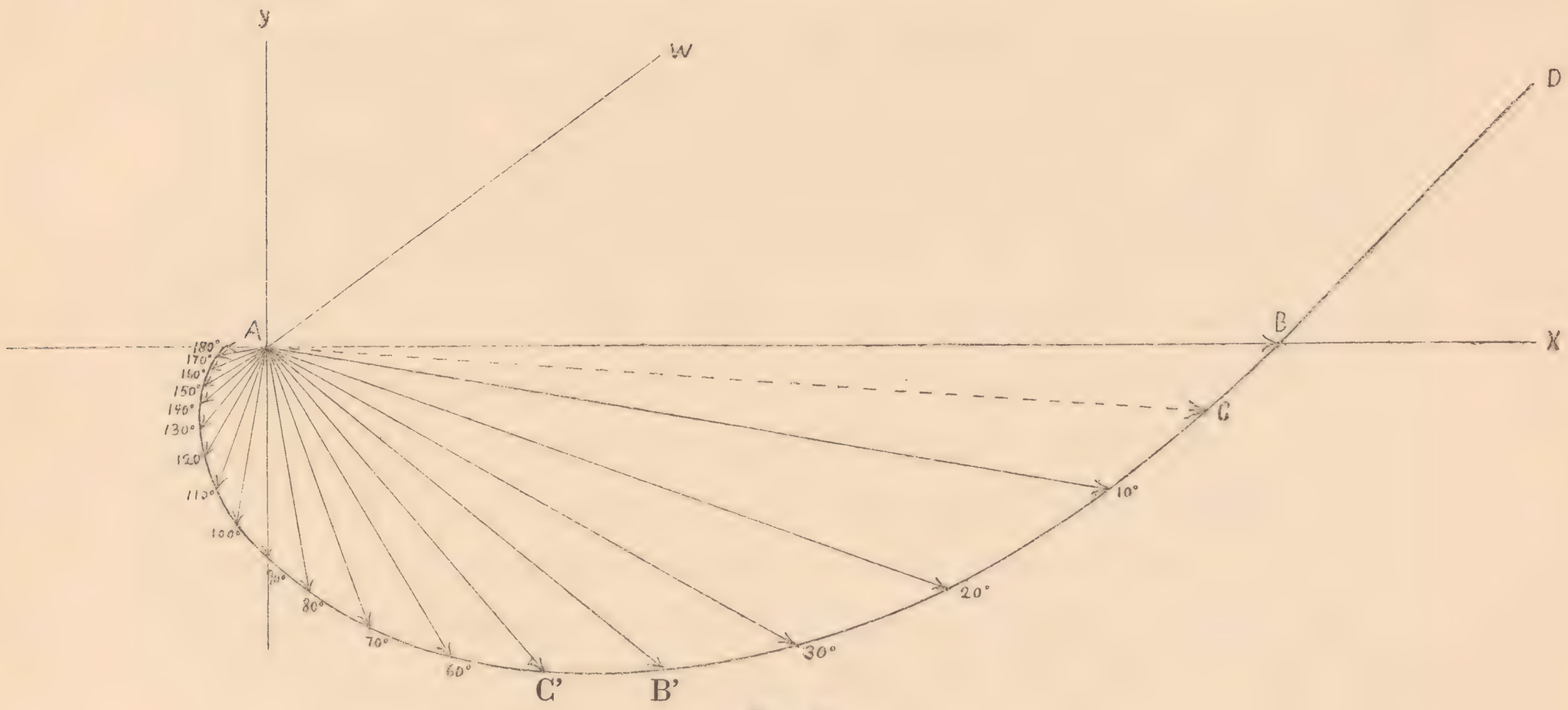

Fig. 5.

for otherwise the particle at C' would have travelled along AB'. If we let the x-axis of our formula be directed along AB', *i. e.* $z = o$, we have $\frac{du}{dz} = -\frac{dv}{dz} = -aC$. From this it follows that the tangential pressure on a water layer, which is directed along the tangent to the curve, must form an angle of 45° with AB', *i. e.* with the direction of the current, at any depth, and this will also be the case at the sea-surface. The force that prevents the water-particles of the surface, at B, from following the direction of the underlying water-stratum AC must consequently be directed along

[1] The water-strata are naturally assumed to be so thin, that their mass and inertia may be left out of consideration.

the tangent *BD*. This force consists, however, of the friction produced by the difference between the velocities of the moving air (the wind) and the surface-current of the sea; the angle α between the direction of the wind and that of the surface-current must consequently be conditioned by the ratio of the wind-velocity to that of the surface-current. Let this ratio be f; α may then be found from the following formula:

$$\sin\,(45^\circ - \alpha) = \frac{\sin 45^\circ}{f},$$

which is simply obtained from the law that the ratio between the sines of two angles in a triangle, is as the ratio between the opposite sides, which in this case is f. If we asume that $f = 50$, *i. e.* a wind-velocity of 1 m. per second is able to produce a stationary surface-current of 2 cm. per second, we find that $\alpha = 44^\circ\ 11'$. If f be 25, $\alpha = 43^\circ\ 23'$; and if f be 5, $\alpha = 36^\circ\ 52'$. We do not know what f may be in the case of a perfectly stationary motion, or whether it is independent of the wind-velocity; but it does not seem probable that it can ever be so small as 5, *i. e.* that the constant wind-velocity should be only 5 times greater than the velocity of the stationary surface-current produced; and thus the angle α should always be greater than 37°. But as the wind-effect varies inversely as $\sqrt{\sin \beta\, K}$, where β is the latitude, and K the coefficient of friction,[1] it is clear that α will to some small extent increase with increasing latitude, and will also depend on the magnitude of the frictional resistance; α will consequently approach 45°. If the ratio f varies with the wind-velocity, it is clear that α will also, to some small extent, vary with the wind-velocity. It should, however, be remembered that we do not generally at sea determine the actual direction of the wind, but that which the wind has relative to the moving sea surface, the effect of the current being not eliminated. This relative wind-direction is the tangent *BD* of fig. 5, and should consequently form an angle of exactly 45° with the stationary surface current.

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[1] Let v_0 be the velocity of the surface-current produced by the wind, and we have $v_0 = \frac{T}{\sqrt{2\ \omega\ \sin\ \beta\ K\ q}}$, where T is the tangential pressure of the wind upon the sea-surface, and q the density $S\,\frac{t}{4^\circ\,\mathrm{C.}}$ of the sea-water. This formula is only correct provided that the frictional resistance be in direct ratio to dv, which, however, is not probable.

The above formula loses its significance if $\beta = 0$; for the motion is assumed to be stationary. But as a permanent force (the wind) is acting upon the water, a stationary motion is impossible unless this force is counteracted by another force. If the sea were sufficiently shallow, this counter force might be the friction against the bottom, and the internal friction of the water arising therefrom. We have, however, assumed that this friction against the bottom does not exist, and have substituted for it the deflecting force arising from the Earth's rotation, which is transferred from one water-stratum to another by the internal friction. The counter force conditioning a stationary motion is then the friction between water-strata moving in different directions. If there be no deflecting force, as is the case at the Equator, there will be no such friction due to the different directions of the motion of the water-strata; and a stationary motion can only be conditioned by the friction against the bottom. But a stationary motion solely due to the friction arising from the downward-increasing angle of deflection, is possible as soon as there actually is a deflection, however small it may be; for the force of deflection is determined by the latitude (β), the relative velocity of the body in the tangential plane, and its inertia; and if $\omega \sin \beta$ be small, this is counterbalanced by the circumstance that the motion may be transferred so much the deeper, and a much greater mass of water will thus counteract the pressure of the wind by its deflecting force. The only condition for the attainment in this manner of a stationary motion near the Equator would therefore be that the Ocean be sufficiently deep and wide. But as the theoretical ratio (f) of the wind-velocity to the stationary surface-current produced by the wind, decreases towards the Equator, it is clear that α at the surface must also, to some small extent, decrease correspondingly.

That the above results of our calculations are correct, may also be seen in the following manner. The forces acting upon a surface water-stratum moved by a certain wind, under the presupositions stated on p. 370, are the *tagential pressure* of the wind upon the sea surface, the *deflecting force* arising from the Earth's rotation, and the *frictional resistance* from the water-stratum underlying the stratum in question. If a stationary motion be attained, these three forces must counterbalance each other. Let g^1 be the mean acceleration which the resultant of the tangential wind pressure and the frictional resistance of the underlying water, is able to give a surface water-

stratum of a certain thickness, then, in case of stationary motion, we have $2 v \omega \sin \beta = g^1$, if v be the velocity of the centre of inertia of the moving water stratum. This velocity must consequently be directed 90° towards the right of the resultant of the tangential pressure and the frictional resistance. Let T_0 be the tangential pressure of the wind on the sea surface (per square unit)

„ T_z —„— —„— water on the underlying stratum at the depth z.

„ $-T_z$ —„— —„— underlying stratum upon the overlying water stratum at the depth z (consequently $= T_z$, but in the opposite direction.

Let these forces be determined both as to magnitude and direction. Let $T_0 - T_2$ express the resultant of T_0 and T_z, both as to magnitude and direction ($= g^1$ multiplied by the mass of the water stratum between 0 m. and z). Let furthermore $v_{0,z}$ be the velocity of the centre of inertia of the moving water-stratum between the surface and the depth z, and q the density of the water $(S \frac{t}{4^\circ \text{C.}})$. The condition for stationary motion must then be,

$$T_0 - T_z = q z 2 v_{0,z} \omega \sin \beta .$$

and $v_{0,z}$ must be directed 90° towards the right of the resultant $T_0 - T_z$.

Fig. 6, 7, and 8 are examples of what has just been stated. Fig. 6 demonstrates the direction of the forces in a very thin water-stratum, fig. 7 in a somewhat thicker stratum, and fig. 8 in a stratum so thick that the motions (v_z) at its lower surface forms and angle of 180° with the motion (v_0) on the upper surface. The greater z is, the smaller becomes T_z, and if a sufficiently thick water-stratum be considered, $v_{0,z}$ will be directed 90° towards the right of the tangential wind-pressure T_0; as in fig. 8 where $T_0 - T_z$ has the same direction as T_0.

The angle of deflection, α, of drifting ice which is in stationary motion, carried along by a constant wind, and which covers the whole sea-surface, will theoretically be greater than α of an open water-surface, provided the tangential wind-pressure be the same on the ice-surface as on the sea-surface —and the angle will increase, with the thickness of the ice. Let α be the angle which the drifting ice is deflected towards the right of the tangential wind-pressure. Mr. Ekman has then found, that provided the tangential pressure of a constant wind on the ice-surface be the same as on the sea-surface then

$$\tan \alpha = 1 + 2M \sqrt{\frac{\omega \sin \beta}{Kq}}$$

where M is the thickness of the ice multiplied by its specific gravity; K is the coefficient of friction; q is the density $(S\frac{t}{4})$ of the sea-water.[1]

Thus the α of drifting ice covering the whole sea-surface is at any rate somewhat greater than the α of the surface-water in an open sea, provided

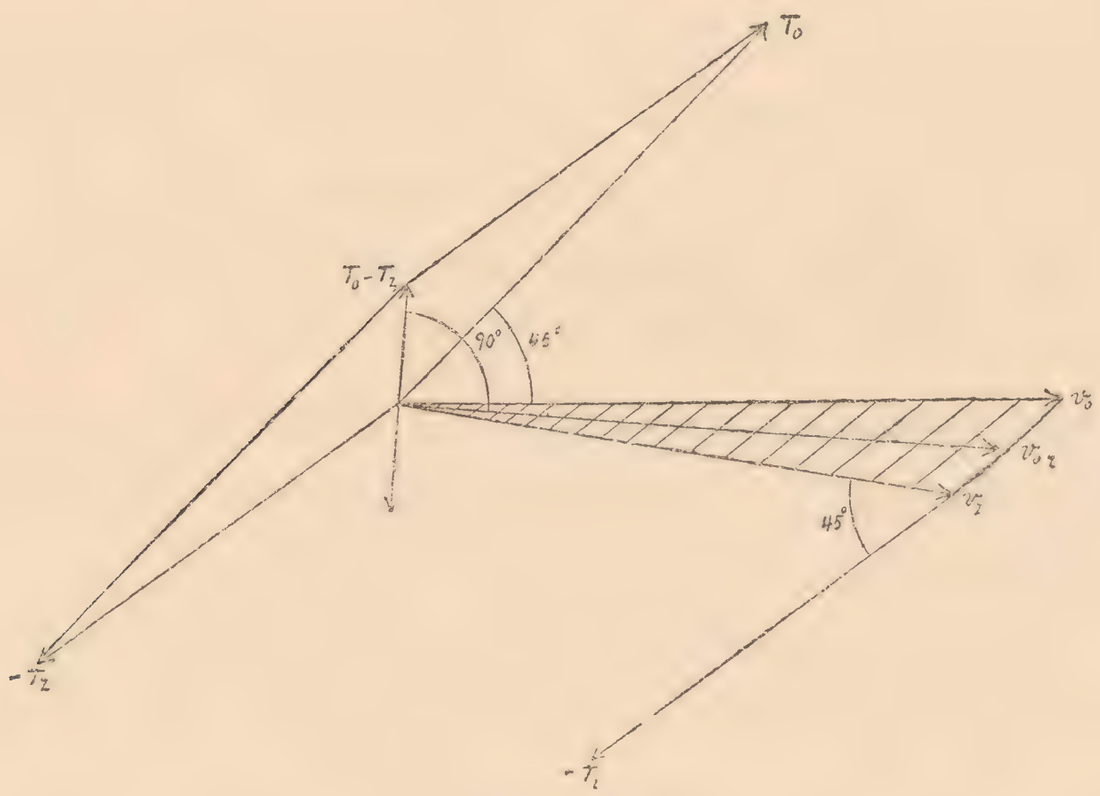

Fig. 6.

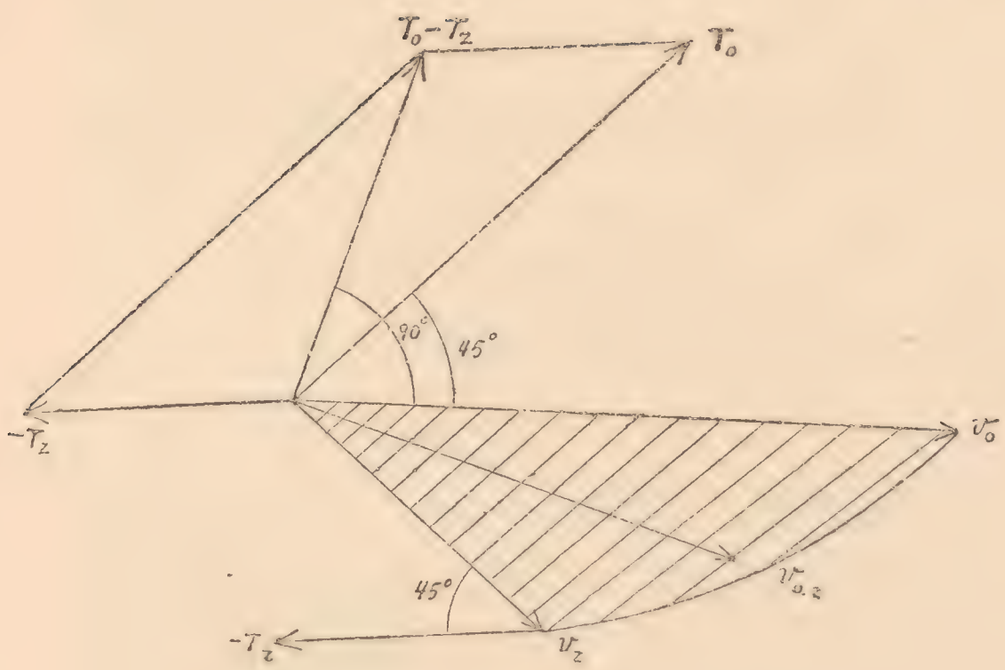

Fig. 7.

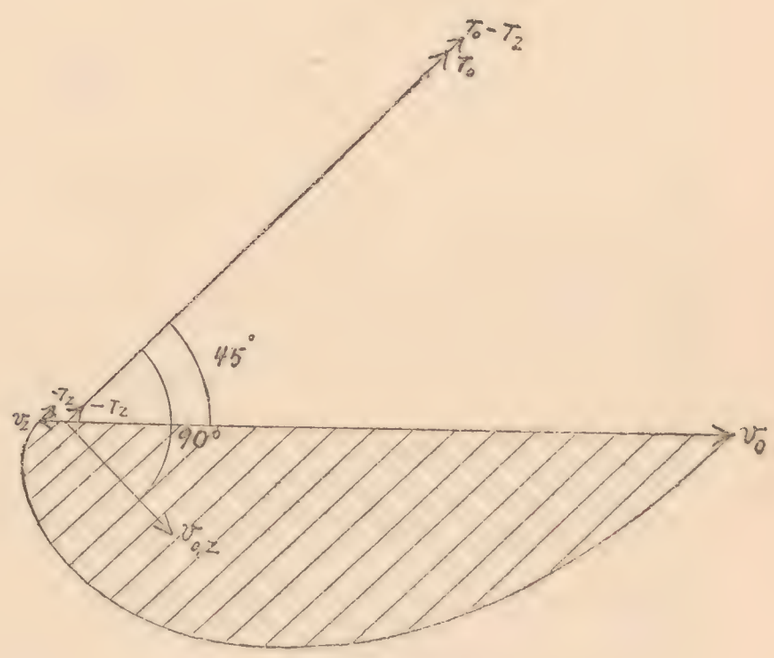

Fig. 8.

that the ice be not very thin with a rough upper surface, and also provided that no formation of waves and consequent stirring of the water-strata occur

[1] As the waves on the sea move along in the same direction as the wind, and often at nearly the same rate, they offer much less resistance to it than the ridges and hummocks of the ice-surface. The tangential pressure of the wind on a rough ice-surface is certainly much greater than on a sea-surface, and therefore the above formula is probably not quite correct.

in the open sea. If this does occur, it means that a thicker layer of water is put in direct motion, and if the thickness of this layer approximates to that of the ice, the result will be the same if the difference in the tangential wind-pressure be not considered. The resistance of the ice itself, caused by meeting land, or other ice with less motion, will tend to diminish α, provided that it acts in the direction exactly opposite to the motion, for this resistance will have the same effect as an increase of the frictional resistance (between water and ice); but will also be able to diminish α below 45°

The conditions of the above calculations were on the one hand that the motion had become stationary, and on the other hand that the motion of the water (or the ice) was at no depth resisted by land, or by water (or ice) with no motion, or with a different motion.

None of these conditions are fulfilled in reality, and this will as a rule tend to diminish the angle of deflection. The motion will probably never approach its stationary state, as the winds never blow during sufficiently long periods, and α will consequently be smaller than calculated above; when the force of the wind begins to act α is naturally zero. A probably still more important fact is that there is always resistance against the motion. The Ocean is bounded by continents, and the same winds do not blow over the whole sea-surface, but over more or less limited areas. If the wind blow along a coast, and the coast be on the right, the deviating water will be pressed up or accumulated against the coast; if the latter be on the left hand, the deviating water will tend to lower the sea-level; in both cases the angle of deflection, α, may be much diminished, especially at small depths, and the water-particles of the upper strata may thus in some cases be forced to flow more or less in the same direction, which may approach that of the wind. The deeper strata with slow velocities will move more freely, but on the other hand they will be influenced by the pressure due to the accumulation of the surface-strata. If the winds blow from or towards the coast, it will naturally depend on the position of the latter, whether α may be increased or diminished by the resistance. According to what has been said above, it might even be possible that, if the wind form a certain angle with the coast, the upper water-strata may be deflected by the land towards the left of the wind, while below a certain depth they will be deflected towards its right.

As the winds from one direction always blow over a more or less limited area, it is clear that the water-particles of the different depths (or the ice) put in motion by the wind, will meet, outside this area, with other water-particles (or ice) which have a different motion, or were originally at rest.

Let us assume the latter case as the simplest. The moving water-particles will try to give the other water-particles their own motion, and they will naturally influence each other, until, if a stationary motion is to be attained, a complete circulation of the Ocean is established. It is clear that where moving water-particles meet particles with no motion, an accumulation ('Stauung') by compression will take place in the respective water-strata, and this accumulation will on the one hand tend to diminish the angle of deflection of the respective water-strata, and thus force the water-particles to move in a direction nearer to that of the wind; but on the other hand, the accumulation will also tend to move the water-particles originally at rest outward in the direction of the originally moving particles. The final result will naturally to a great extent depend on the configuration of the coasts bounding the sea-basin. It is clear that a stationary motion with such great angles of deflection of the different water strata as the above formula would give, will not as a rule be attained; but on the other hand, it is also clear that the angle of deflection will always, especially in the open sea far from coasts, have a strong tendency to increase with the depth, if the current be due to the wind.

After this theoretical discussion of the problem, let us consider our observations during the drift of the Fram. It is a striking fact that while there is a considerable deflection of the drift-resultant towards the right of the wind-resultant for all shorter periods, with only a few exceptions, this is not the case for the longer periods (see the 6th column of the Table p. 366). This circumstance is naturally due to the effect of the permanent current. In order to find the direction and velocity of the ice-drift produced merely by the winds, it is necessary to reduce the observed drift for each period by the distance which the ice would travel during the same period, if merely carried by the permanent current. If this be done graphically, we easily find the direction and magnitude of the real wind-drift (*i. e.* the ice-drift produced merely by the wind), provided that the direction and velocity of the permanent current be accurately known. Using the values of the

current given in the Table on p. 361, this has been done for the different periods; and the results are given in the 11th, 12th and 13th columns of the Table (pp. 366—368). The 13th column gives the angles of deflection (α) of the wind-drift.

For the whole drift from Nov. 7th, 1893, to June 27th, 1896,[1] we find that $\alpha = 37{\cdot}°5$. This does not differ greatly from the values which might be obtained by our theoretical calculations above, if it be remembered that this wind-drift was the result of winds changing much in direction, so that consequently the motion probably never reached its stationary condition; and on the other hand the winds naturally always blew over more or less limited areas. The mean value of α for all shorter periods during the whole drift is smaller, viz. $\alpha = 28°$. This is also natural, for it is probable that during the many very short periods that are here taken into account, the motion has been still less stationary, and the areas of the winds were more limited than that of the prevailing wind during the whole drift.

If we do not consider the first part of the drift before November 23rd, 1893,—when it was comparatively irregular from the fact that northerly winds had too much effect owing to the open sea to the south—and we calculate the angle of deflection, α, for each year, we find that α for the first year (Nov. 23rd, 1893—Nov. 23rd, 1894) is noticeably smaller (+12°) than those of the other years, α of the second year being greatest (+40°, see the Table). By taking the means of all shorter periods of the Table, for the same years we find

	Mean daily Wind-Drift in naut. Miles.	Mean Drift produced by Wind of 1 m. per Sec.	α
Nov. 23, 1893 – Nov. 23, 1894	2·38	0·806	26°
Nov. 24, 1894 – Nov. 28, 1895	2·66	0·773	34
Nov. 28, 1895 – Nov. 27, 1896	3·15	0·787	23

We see that, calculated in this manner, α of the first year is not smaller than that of the last year, but α of the second year is in both cases greater than those of the two other years.

[1] The period before Nov. 7th, 1893, is not considered, as we had then much open water to the south, which greatly influenced the effect of the northerly winds.

These differences, if they are not merely accidental, can hardly be due to any difference in the rate of the drift, even if the magnitude of α really could be influenced by this rate. We see that the mean daily wind-drift in the prevailing direction increases for each year. If, however, we assume that α varies inversely as the velocity of the drift it is clear that it will make a great difference in α, whether an ice-floe travels during a certain interval of time directly to a certain point with a relatively slow velocity, or whether it reaches the same point by a much longer route, and consequently with a much greater velocity. If we wished to arrive at any certain conclusion in this respect, we should have to measure the whole drift with all its détours, and to eliminate the drift caused by the permanent current. As this work would require too much time, we may arrive at a sufficiently accurate result by taking the means of the wind-drifts of the several shorter periods, as is done in the small table above.[1] The values thus obtained will naturally be somewhat too small, as all the smaller détours are neglected; but we see that the mean daily wind-drift increases for each year, and this may indicate that the angle of deflection probably does not vary inversely as the rate of the drift; but the differences are too small to give any certain information in this respect.

We have seen above that α will have a tendency to vary as the thickness of the drifting ice, and inversely as the resistance opposing the motion of the ice. On the one hand the thickness of the ice was naturally least the first winter,[2] and increased each year,[3] while the resistance to the drift in the prevailing direction was probably greatest in the beginning of the drift, when there was most ice in front to be put in motion. The correctness of

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[1] The actual drift (wind-drift + drift due to current) for each year is, for the
first year, Nov. 23, 1893—Nov. 23, 1894, 992 naut. miles, or 2·718 miles in 24 hours.
second „ „ 23, 1894—Nov, 23, 1895, 1000 —„— 2·740 —„—
third „ „ 23, 1895—June 27, 1896, 653 —„— 2·980 —„—

[2] The reason why α for the first winter (Oct. 1, 1893—June 1, 1894) is nevertheless greater (+38°) in the Table than α for the other winters, is that during the first weeks, from October 1st to November 23rd, 1893, the conditions were exceptional, with prevailing northerly winds which had relatively too great an effect, owing to the open sea towards the south. The backward drift was therefore comparatively too great during this period, and thus α becomes too great.

[3] The roughness of the under side of the ice will naturally also be of importance in this respect, for the deeper the projections reach into the underlying water, the greater will be the bulk of water that is directly carried along with the ice, and the more will the α of the ice be increased, as it will to some extent be equal to an increase of the thickness of the ice; but on the other hand it will also increase its frictional resistance.

this assumption seems to be proved by the effect of the wind (see later). Thus it might seem natural that α for the resultant of the wind-drift for the first year should be smaller[1] than that of the second year. But on the other hand we have seen that the farther the motion is from being stationary, the smaller must α be. The winds were comparatively strong, and very variable in direction and force, during the last year, and thus the motion of the ice has probably, during most periods, been relatively far from stationary. This may explain why α is smaller for this year than for the second year, although the ice was certainly thicker, and the resistance to the motion of the ice smaller, as there was more open water.[2]

We cannot expect the values of α for shorter periods to be very regular, as they are naturally to some extent determined by forces which we do not know, *e. g.* the resistance to which the ice is exposed at the time, the winds blowing in neighbouring regions of the sea, etc. Nevertheless there are very few exceptions to the rule that the wind-drift deviates towards the right of the wind, and some of the exceptions and irregularities are easily explained.

We have pointed out above that during the first part of the drift, northerly winds had a relatively greater effect than other winds, as they blew towards open water. This explains why α is relatively great for the period from September 29th, 1893, to January 9th, 1894, and is negative for the period from December 12th to 31st, 1893. The exceptions during the periods from December 15th to 21st, 1895, and from April 27th to May 19th, 1896, may perhaps also be explained in a similar manner.

The drift-resultant for the period from November 7th to November 23rd, 1893, deviates regularly ($\alpha = 40°$) from the wind-resultant. On November 23rd, 1893,

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[1] That α of the prevailing drift of the first year is so very small (+12°) may be due partly to the circumstance that the current during the first periods after November 23rd, 1893, near the continental slope, was probably very westerly, making α for these periods very small (+6° for Nov. 23rd - Dec. 12th, 1893; —2° for Jan. 15th—Febr. 22nd, 1894), and partly to the fact that the resistance to the motion of the ice was greater towards the north than towards the south, and therefore $\alpha = -63°$ for Dec. 12th—Dec. 31st, 1893. These irregularities in the first period affect the mean of all the shorter periods during this year less, and therefore this mean (+26°) is greater than α for the prevailing drift. If the value of α for the first irregular periods be left out, α becomes greater for the first year than for the second year.

[2] More open water between the flocs has, however, on the other hand a tendency to diminish α, as the less continuous the ice sheet covering the sea is, the more difficult will it be to give the underlying water a stationary motion. The drift-direction of single ice-floes sailing for the wind in a comparatively open sea, with no surface-current, will naturally not be far from the direction of the wind.

(78° 30′ N., 139° 34′ E.) there is, however, a sudden change in the direction of the drift, which is evidently caused by currents, for there is no equally great change in the direction of the wind. And for the period from November 23rd to December 12th, 1893, α becomes very small (+6°). It seems probable that at this place, where the ice has come north of the latitude of the unknown north point of Bennett Land situated to the east,[1] and where the sea suddenly becomes deeper, the northward-drifting ice has suddenly been exposed to a surface-current coming from the east, north of the shallow platform on which Bennett Land, the New Siberian Islands, and Sannikoff Land are situated. Farther south, the lands and the shallow platform to the west sheltered the drift of the ice more or less from the effects of this current from the east. If this conclusion be correct, it seems to prove that Bennett Land can have no great extension towards the north.

d. *The Relative Velocity of the Ice-Drift produced by the Wind.*

The tangential pressure with which the wind acts upon the ice is probably in direct ratio to the square of the wind-velocity. The resistance of the underlying water to the motion of the ice is possibly in direct ratio to the square of the drift-velocity. If this be correct, *the velocity of the drift produced will be in direct ratio to the velocity of the wind.* This seems very natural, because the resistance which the wind meets with over the rough ice-surface will probably increase in a similar ratio as the resistance of the water to the rough under-surface of the ice.

A simple method to express the ratio of the wind to the drift it produces, is then to calculate what drift a wind with the same relative effect, but with a velocity of 1 m. per second, would produce in 24 hours.

This has been done for the different periods, and the values obtained are given in the twelfth column of the Table on pp. 366—368.

If we divide the winds into three classes according to their velocities, and take the means of their effects out of this column, we find

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[1] The south point of Bennett Land is situated in Lat. 76° 38′ N., and Long. 148° 20′ E.

Wind Velocity	Mean daily Drift produced by Wind of 1 m. per Second	α
0—2 m. per Second	0·95 naut. Mile	+ 9° 50′
2—4 m. „ „	0·78 „ „	+30 28
above 4 m. „ „	0·94 „ „	+34 27

We can hardly expect a closer agreement than between 0·95 mile, 0·78 and 0·94 mile, and our above assumption that the wind-drift produced will be in direct ratio to the velocity of the wind, seems to be fairly well confirmed. It may nevertheless be objected that the mean value of the effects observed for the weaker winds may be less trustworthy, as there the accidental influences of winds in neighbouring regions, etc. may be of more importance; and the circumstance that the mean daily effect of wind-velocities above 4 m. per second, is 0·16 mile greater than that of wind-velocities between 2 and 4 m. per second, may therefore possibly indicate that the relative effect of the wind increases somewhat with its velocity.[1] But this difference is not at any rate so great that we need take it into consideration at present.

The mean relative drift during the whole drift-voyage, produced by the prevailing wind, if it had a velocity of 1 m. per second, is 0·69 nautical mile in 24 hours. But if we take the mean of the values for all shorter periods during the same time, we find the relative wind-effect produced by a wind-velocity of 1 m. per second to be 0·85 mile in 24 hours. The reason why the latter value is higher than the former, is evidently that the ice will offer less resistance to winds blowing in different directions (there will be more openings in the ice for the wind to close), than to the prevailing wind carrying the ice continually in one direction where the ice will be pressed more together. There is also a striking difference between the relative wind-effects (of wind of 1 m. per second) of the different years. For the first year it was 0·54 mile in 24 hours, for the second year 0·68 mile, and for the third year it was 1·19 mile. The explanation may be that the resistance of the ice to the prevailing wind was greatest the first year and comparatively very small the last year, when there were evidently many openings between the

[1] If the above values be correct, the drift produced by the wind would not increase as v^1, but as $v^{1 \cdot 096}$, if v be the velocity of the wind.

ice-floes towards the sea north and north-west of Spitsbergen, in which direction the velocity of the permanent current was increased. The means of the relative wind-effects (per wind of 1 m. per second) for all shorter periods of the three years are more alike; they are 0·806, 0·773, and 0·787 mile in 24 hours (see p. 376).

Prof. Mohn (l. c., p. 116) has mentioned that "the rough surface of sea-ice exerts a greater resistance to the motion of the air than does even the most agitated sea", and he quotes Scoresby's remarks on this subject.[1] It is a well-known fact amongst all ice-navigators, that the wind has strikingly less velocity in or near the pack-ice than over the open sea.[2] On board the Fram it was also noticeable how very much stronger the wind always was at the mast-head than near the surface of the ice.[3]

Mohn considered this to be of importance as giving the wind less velocity, and he moreover maintained "that the power of the wind to set in motion an ice-encumbered sea should result in a slower rate than with a sea free of ice" (l. c., p. 119). This is only correct for the uppermost surface-layers, and even there it may be doubtful, for the tangential pressure of the wind on the surface of the water is much smaller than on the rough ice-surface, and is moreover to a great extent transformed into wave formation in the open sea, which is not the case in an ice-covered sea. On the other hand the α of ice may be greater (cf. above), and the water naturally offers a great resistance to the rough under-side of the ice, and much turbulent motion is thus produced. The hummocks and unevennesses on the upper surface of the ice act as sails, and the projections on its rough under-surface as stirrers of the water. The floating ice may perhaps reduce the velocity of the drift of the uppermost water-layer, but it will at any rate increase the velocity of the whole bulk of the upper water-layer, as it will directly transfer the effect of the wind to a much greater depth than the friction of the water is able to do.

From 658 observations made in the equatorial regions Mohn (l. c., p. 118) calculated that on the average a wind-velocity of 1 m. per second would

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[1] An Account of the Arctic Regions, vol. I, pp. 296, 297.

[2] This is perhaps caused not only by the roughness of the ice-surface, but also partly by the cold air over it forming to some extent small local anticyclones.

[3] This circumstance may to some extent explain why the mean velocity of the wind in the North Polar Basin is so unusually small, although the chief cause is probably the uniformity of the meteorological conditions over an extended area.

produce a surface-current with a velocity of 1·5 nautical miles in 24 hours (3·22 cm. per second). Prof. Krümmel[1] has pointed out that as Mohn has used Scott's Table for converting the Beaufort Scale to velocity in metres per second, he has arrived at too high values for the mean wind-velocity, and has consequently obtained too low values of the current produced by the wind. According to Krümmel, a wind-velocity of 1 m. per second should thus according to the above equatorial observations produce a current with a velocity of 2·19 miles in 24 hours, or 4·66 cm. per second.

Whether we take Mohn's or Krümmel's values, however, there are, according to my view, two chief objections to be made to these calculations, rendering them valueless for our purpose. On the one hand, Mohn has excluded all observations made during periods when the wind deviated much from the direction of the current; the values obtained cannot therefore be the effect of the prevailing wind, if the currents observed were entirely due to the effect of the wind: the values must then be too great. On the other hand, he has assumed that the equatorial currents are produced solely by the local winds, an assumption which must necessarily lead to erroneous results; for even if the circulation of the Ocean were simply due to the effects of the atmospheric currents, it seems probable that the permanent equatorial currents would also be much influenced by winds prevailing in neighbouring areas of the Ocean. But even though the atmospheric circulation may have much influence upon the oceanic circulation, it is equally certain that this is to a very great extent determined by other forces—especially by the convectional movement in the Ocean itself in connection with the Earth's rotation—which according to my view, are of great importance. The values of the wind-effect upon the surface-current obtained by Krümmel's and Mohn's calculations are therefore much too high; and more interesting results might perhaps have been obtained if the effects of the winds had been calculated for periods when the direction of the wind differed from that of the current, as the effect of the permanent current could then be more easily eliminated.[2]

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[1] Boguslawski and Krümmel, Handbuch der Ozeanographie, vol. II, p. 370. See also Georg Wegemann, 'Die Oberflächen-Strömungen des nordatlantischen Ozeans nördlich von 50° N. Br.' Altona, 1900, p. 12.

[2] But it would at any rale be a mistake to assume that the values of the wind-effect thus obtained could be applied without alteration in all latitudes (cf. p. 384).

From the observations of Sir Leopold M'Clintock made during the drift of the Fox in Baffin Bay and Davis Strait (1857—58), Mohn has calculated that in this sea a wind-velocity of 1 m. per second should produce a mean drift of the ice of 0·36 nautical mile in 24 hours. Mohn has, however, left out the observations of October and November, when the direction of the drift deviated considerably from the mean direction of the wind; if these months had been considered, the relative effect of the wind would have been still less, but even then we would get no mean for the whole year, as there were no observations during the four months from May to August.

On the other hand, Mohn has used Scott's table for converting Beaufort's Scale to wind-velocity in m. per second, and has probably found too high values for the winds, which will give too low values for the relative wind-effect. One chief difficulty is, however, that the velocity of the permanent current in the sea has not been determined.

At any rate, we see that the ratio of the drift to the wind seems to have been noticeably less during the drift of the Fox than during that of the Fram.

Having at present no trustworthy observations for determining the effect of the wind upon the surface-current in an open sea, it would be of interest to know whether the results of our observations in an ice-covered sea are applicable to other parts of the Ocean. It seems to me probable, according to what has been said above, that in an ice-covered sea wind of a certain velocity must, if anything, have a greater effect in producing a surface-current of some depth, than the same wind over an open sea, if it were not for the angle of deflection and the resistance of the ice itself. The latter may, however, be considerable, and we have seen that it probably reduced the effect of the prevailing wind during the first year nearly to the half of what it was during the last year. It may, however, be doubtful whether this resistance of the ice-covering is sufficient to reduce the mean effect of the wind upon the drift-current in the North Polar Basin to the same relative velocity as the surface-current produced would have in an open sea.

It is evident that the effect of the wind upon the drift of the ice or the surface-water will vary to some extent inversely as the latitude. If we call the velocity of the stationary surface-current produced by a wind of a

certain strength in an open sea v_0, we have, according to Mr. Ekman's calculation,

$$v_0 = \frac{T}{\sqrt{2\,\omega \sin \beta\, K q}}$$

where T is the tangential pressure of the wind upon the sea-surface. The friction of the water is here assumed to be in direct ratio to $d\,v$, *i. e.* K is independent of the differences of velocity.

If the sea be covered with ice, the effect of the wind (v_0) will be decreased, as the angle of deflection (α) increases. For this reason it is possible that the drift produced by the wind in the North Polar Basin, is comparatively slower than the uppermost surface-current would have been if the sea had not been covered with ice, leaving out of consideration that the rough ice-surface offers more resistance to the wind (cf. above p. 383). But let us assume that the conditions are equal. We see then that if the relative wind-effect (surface-current produced by wind of 1 m. per second) be 0·69 mile in 24 hours in 83° N. Lat., as found for the prevailing wind of the whole drift, the relative wind-effect, in 30° N. Lat. would be $= 0{\cdot}69 \sqrt{\frac{\sin 83^\circ}{\sin 30^\circ}} = 0{\cdot}97$ mile in 24 hours, and in 10° N. Lat. it would be 1·65 miles in 24 hours.

If we assume the relative wind-effect to be 0·85 mile in 24 hours in 83° N. Lat. (as found by taking the means of all shorter periods), we find in a similar manner that the relative wind-effect in 30° N. Lat. would be 1·20 miles and in 10° N. Lat. 2·04 miles in 24 hours. If the relative wind-effect be 1·19 miles in 24 hours in 83° N. Lat. (as found for the last year, but which is evidently too high, cf. pp. 361, 380, 382), it would give us a wind-effect of 1·68 miles in 24 hours in 30° N. Lat., and 2·85 miles in 24 hours in 10° N. Lat.

T does not depend on the wind-velocity only, but on the difference between the velocities of the wind and the surface current produced; and this difference will to some extent increase with the latitude, but the error thus arising will be of little importance.

e. *The Power of the Wind to produce Surface Currents, and the Depth of Wind Currents.*

Our observations during the expedition are perhaps the only observations known, that may give some trustworthy information as to the power of the

wind to produce surface-currents. It is, however, evident that this power, if we wish to know what volume of water the wind is able to put in motion, will depend on the rate at which the angle of deflection, α, increases with the depth. We have repeatedly pointed out that α of a wind-current must actually increase with the depth; for just as the surface-water is deflected towards the right of the direction of the wind, so each moving water-stratum will be deflected towards the right of the motion of the overlying stratum by which it is put in motion. This fact will naturally limit the power of the wind to produce currents, and previous authors, in discussing this problem, have evidently made a mistake in not taking this circumstance into consideration, and have therefore arrived at impossible results by their calculations (*e. g.* Zöppritz). To express the matter briefly, it would be of interest to calculate the thickness of each water-stratum where the difference of α is equal to 1°, or to determine the depths at which α is 90° or 180° greater than at the surface.

Mr. *V. Walfrid Ekman* has done me the great favour of making the following calculations. The presuppositions are the same as those mentioned on p. 370. We find then that if the *depth of the surface-current* produced by the wind, be assumed to be that at which the direction of the current is deflected 90° from that of the motion on the surface, *i. e.* where $u = 0$, and v is directed along the negative y-axis, we have, according to the formula on p. 370, for the lower boundary of the surface-current,

$$a z = \frac{\pi}{2}, \text{ and hence}$$

$$z = \frac{\pi}{2}\sqrt{\frac{K}{q\,\omega\,\sin\beta}}$$

that is, provided that the frictional resistance is in direct ratio to $d\,v$; if it is as $(d\,v)^2$, the depth, z, will be increased with the velocity of the wind. If $K = 0{\cdot}018$ be introduced into the above formula, we find that at the Pole ($\beta = 90°$) $z = 0{\cdot}24$ m., and in 10° N. Lat. $z = 0{\cdot}58$ m. The velocity of the current would at these depths be about one fifth of the surface-velocity. As α increases regularly with the depth, we find that in 0·5 m. at the Pole, α would be 180° greater than on the surface, and the velocity of the current would be about $1/27$ of the surface-velocity.

These theoretical values of the depth of the stationary wind-current are of course absurd. In reality it generally becomes much deeper, chiefly per-

haps because α is diminished by the resistance of lands, and of the water in other regions of the Ocean, etc. But it is also probable that the assumed K is much too small, and Mr. Ekman has therefore, at my request, made an attempt to calculate K from our observations.

If we assume that the permanent surface-current observed by us in the North Polar Basin had acquired a stationary condition, that it is produced by the force of circulation calculated in the section along the Fram's route (see p. 354), that it is forced, by the configuration of the surrounding coasts and the bottom, to follow very nearly the direction of this force, and that there is no resistance but the friction between the horizontal strata, we may be able to calculate the coefficient of friction (K), if we assume the thickness of the surface-current to be 200 m.[1] and the velocity of the current to be zero at 200 m.

If there be no tangential pressure (by wind) at the sea-surface, and if we assume that the surface-water down to 200 m. flows as homogeneous water over a bottom (as in a river 200 m. deep), we find that[2]

$$K = \frac{g\,h}{2\,v_0},$$

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[1] The thickness of the surface-current evidently varies according to the situation of the stations along the Fram's track. If we assume that the lower strata of the cold surface-current are much intermixed with water from the upper strata of the warmer under-current, the vertical distribution of temperature and salinity will inform us where the lower limit of the surface-current probably is. The shape of the vertical temperature curves especially (Pls. X—XIII) are very instructive in this respect. We have simply to take the mean of the depths where there is a sudden rise of the temperature from about —1·5° C. towards the maximum temperatures. The approximate depths of the cold surface-currents would accordingly be,

at Stat.	14, 185 m.	at Stat.	20, 165 m,
„	15, 200 „	„	22, 170 „
„	16, 186 „	„	23, 180 „
„	18, 195 „	„	24, 200 „
„	19, 168 „	„	25, 200 „
		„	26, 200 „

[2] If u = the velocity of the current, changing with the depths, z = the height above the under stratum of the surface-current where $u = 0$, and K = the coefficient of friction, we have $\frac{d^2 u}{d z^2}$ = a constant = C; and $K \frac{d^2 u}{d z^2} = -g$ (the acceleration due to the force)

$$\frac{d^2 u}{d z^2} = C$$

$$\frac{d u}{d z} = C z + C_1$$

$$u = C\frac{z^2}{2} + C_1 z + C_2;\ \text{but}\ C_2 = 0,\ \text{as}\ u = 0,\ \text{if}\ z = 0.$$

where g is the acceleration which the force of circulation would produce at the surface, if there were no friction, h is the depth of the current (20 000 cm.), and v_0 the velocity of the current at the surface.

If we assume that the density is gradually increasing from the surface down to 200 m.,—which is more correct—we find that[1]

$$K = \frac{g\,h^2}{3\,v_0}.$$

We have found before (pp. 354, 355) that the acceleration due to the force of circulation of the uppermost 200 m. in a section along the Fram's track, varies somewhat between the different stations. If we assume that the velocity of the current is zero at 200 m., and that the whole calculated force of circulation is spent in forming the surface-current, the acceleration it produces will be about 0·00016, between our Stat. 11 and Arrhenius's Stat. IV, west of Spitsbergen, and between our Stat. 14 and Arrhenius's Stat. IV it would be about 0·00014. If we assume the velocity of the stationary surface-current to be 1·0 nautical mile in 24 hours or 2·141 cm. per second, an acceleration of 0·00014 will give $K = 8718$; if the acceleration be 0·00016, we find that $K = 9963$. One evident mistake in these calculations is that the accelerating force does not only cause the water between 0 m. and 200 m.

If the depth of the current be h, and the velocity at the surface where $z = h$ be v_0, we have,

$$\left.\begin{array}{ll} \text{as } \dfrac{d\,u}{d\,z} = 0 \text{ if } z = h & v_0 = \dfrac{C}{2}h^2 + C_1\,h \\ & C\,h + C_1 = 0 \text{ or } C_1 = -\,C\,h \end{array}\right\} \therefore \frac{C}{2}h^2 = -\,v_0$$

$$\text{as } K\frac{d^2\,u}{d\,z^2} = -\,g \qquad K\,C = -\,g$$

$$K = \frac{g\,h^2}{2\,v_0}$$

[1] We find then that $K\dfrac{d^2\,u}{d\,z^2} = -\,g$, the acceleration due to the force of circulation, will increase regularly from $z = 0$ (*i. e.* at the depth h) towards the surface.

$$\begin{cases} \dfrac{d^2\,u}{d\,z^2} = C\,z \\ \dfrac{d\,u}{d\,z} = \dfrac{C\,z^2}{2} + C_1 \\ u = \dfrac{C\,z^3}{6} + C_1\,z + C_2 \text{ (but } C_2 = 0, \text{ as } u = 0 \text{ if } z = 0.) \end{cases}$$

$$\left.\begin{array}{l} \dfrac{C}{6}h^3 + C_1\,h = v_0 \\ \dfrac{C\,h^2}{2} + C_1 = 0 \text{ or } C_1 = -\dfrac{h^2}{2}\,C \end{array}\right\} \frac{C}{3}h^3 = -\,v_0$$

$C\,h\,K = -\,g$, where g is the acceleration at the surface.

$$K = \frac{g\,h^2}{3\,v_0}$$

to flow in one direction, but it also produces, to some extent at least, a current of compensation in the underlying water, and hence the values of K should be considerably reduced, perhaps to between 4000 and 5000. But even these values of K are of course highly improbable. One error of the calculations may be that the surface-current is far from having reached its stationary velocity, conditioned upon the existing force of circulation. We have also seen before (pp. 323, 346) that underneath the uppermost surface-current, there is a colder current, carrying the water with a minimum temperature, at depths of about 50 and 60 m., and flowing in a different direction, which may tend to complicate the problem.[1]

In Mr. Ekmann's calculations of K, the effect of the deflecting force arising from the Earth's rotation has not been considered. If in an open sea the deflection of the moving waters be not checked by the surrounding coasts and the surrounding water of other parts of the sea, it is clear that the deflecting force ($= 2 v \omega \sin \beta$) could never become greater than the force of circulation, or otherwise α would become greater than 90°. Hence the velocity, v, of the motion would never become greather than $v = \frac{g}{2 \omega \sin \beta}$ where g is the acceleration due to the force of circulation. If g be 0·00014, and if the deflection of the current be not checked by other forces, we see that in the Polar Sea, v would never become greater than

$v = \frac{0{\cdot}00014}{2 \times 0{\cdot}00007\,3 \sin 86°}$ or about 1·0 cm. per second, even if there were no frictional resistance.[2]

In reality the deflection of currents is generally counteracted by lands, etc. But it is clear that if the deflecting force of a current is to reduce the effect of the force of circulation, the current must be directed somewhat towards the right of the latter, and it is then only the deflecting force of the component of the motion that forms an angle of 90° towards the right of the direction of the force of circulation, which counteracts the latter. In our case, where we know the force of circulation in a section along the Fram's track, but where the known surface-current is directed towards the left of this track, the motion of this

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[1] This colder current may, however, to a great extent be a compensating under-current produced by the wind-drift, which has on the whole a more northerly direction than the permanent surface-current, and is compensated by water from regions to the north.

[2] At the Equator where $\beta = 0$ and $\alpha = 0$, v might attain any value if not checked by the friction.

surface-current can have no component that would counteract the known force. But if an under-current filling the whole interval between the surface-current and the bottom, and running in a different direction, has a component directed 90° towards the left of the above force of circulation, the underlying water will be pressed up towards the surface in the direction of the force, and the surface-current will be checked, and ils thickness reduced. This may especially happen on the north ride of the ridge between Spitsbergen and Greenland.

In the North Polar Basin which, as before said, may be considered as a large fjord, the surface-layer of polar water is chiefly obliged to run towards the main entrance to this fjord, *i. e.* the opening between Spitsbergen and Greenland; the surface-current is thus prevented from being very much deflected from the direction of the force of circulation,[1] and the conditions exist for the formation of a surface-current much more rapid than that just calculated. The isopyknals will necessarily arrange themselves in such a manner, that the circulating force in connection with the deflecting force and the resistance from the coasts will carry the water towards the outlet. But the possibility exists that the surface-current is to some extent checked by the under-current, in the manner just mentioned.

There is also another circumstance which may be of importance in this respect. The North Polar Basin may be considered as a large, wide vessel with a narrow outlet at which the outward-flowing surface-current coming from the interior of the wide vessel, is moreover blocked up by the probably shallow sub-oceanic ridge between Spitsbergen and Greenland, by which the resistance is much increased.[2] In this manner the velocity of the surface-current of the interior Basin is evidently much reduced, and it is only natural that the velocity must increase towards this outlet, as we have actually found it to do; and the force is therefore partly spent on accelerating the water. The resistance against the drifting ice from other ice or from coasts may also tend to reduce the apparent velocity of the surface-current. We see the whole problem is an extremely complicated one; and we have too few data to make any trustworthy calculation of K.

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[1] Some deflection does at any rate occur, as is seem from the fact that the Polar Current runs south along the east coast of Greenland.

[2] Cf. what I have said before about the influence of the sea-bottom upon the surface-currents (pp. 260, 336; and also, 'Nyt Mag. for Naturvidenskab', vol. 39, Christiania, 1901, p. 152).

Although on the other hand it seems probable that the force of circulation producing the current may be somewhat greater than is assumed above, as we only know the force calculated in a section along the Fram's track, there can be little doubt but that the above values of the friction are much too high. These values may nevertheless give us an indication that the frictional resistance of sea-currents is very much greater than might be expected from the experimental coefficient of the internal friction of the water. This greatly increased resistance may to a great extent be due to the turbulent motion of the water-particles produced by the gliding of one water-stratum over another.

If, as an experiment, we assume that $K = 4000$ and this value be introduced in the above formula for the depth of the wind-current, we find at the Pole, that at a depth

$$z = \frac{\pi}{2}\sqrt{\frac{4000}{1{\cdot}028 \times 0{\cdot}00007292}} = 116 \text{ m.},$$

the angle of deflection, α, would be 90° greater than at the surface. In 30° N. Lat. this depth would be 164 m., and in 10° N. Lat. 279 m.

But it has been pointed out above that the resistance of the coasts and of the water with different motions in other regions of the sea, may tend to diminish α of the different strata of the wind-current; and this may in some cases increase the depth of the wind-current. The formation of waves on the surface of the sea will also have the same tendency. As we find, however, that in the enclosed North Polar Basin the angle of deflection, α, of the drifting ice has not been more diminished from its theoretical value than to 37·5°, and as the above coefficient of friction is too high, it seems probable at any rate that the wind-currents cannot practically exceed the above depths in the open Ocean.

From what precedes, we may expect that winds have a greater power to produce drift-currents of some depth in the Northern Hemisphere where the sea is bounded by continents, than in the Southern Hemisphere where the sea is circumpolar and there is less resistance from land. But even in the Northern Hemisphere, the depth of the wind-currents is evidently very limited, according to what has been said above; and when we consider that the Gulf Stream is perhaps 600 or 700 m. deep in the Norwegian Sea, it seems probable that only a small portion of this current can be due to the

effect of the wind. The latter is evidently not of such great importance as regards the general circulation of the Ocean as several oceanographers have assumed it to be.

The general rapid increase of the density of the sea-water from the surface downward, in northern and southern seas, will also have a strong tendency to limit the depth of the wind-currents.

In the North Polar Basin, we find that even as regards the prevailing drift of the ice the prevailing winds are of less importance than the permanent current in the water, due to the force of circulation.

We see from the Table (p. 366), that while, during the whole voyage, the current would give a mean drift of 0·73 nautical mile in 24 hours, the prevailing wind would produce a mean drift of 0·52 naut. mile daily. During the first year the mean current-drift would be 0·54 naut. mile, and the wind-drift 0·41 mile, during the second year 0·78 mile and 0·61 mile, and during the third year 0·98 mile and 0·70 mile.

The actual drift is the resultant of the two forces. One effect of the winds which was of interest for the Fram expedition was that they carried the ice considerably farther north than the current alone would have done, starting from the same point.

f. *The Rate of the Warm Under-Current.*

We have seen that the surface-drift of the North Polar Basin is to a very great extent due to the permanent surface-current arising from the force of circulation, which we have calculated, although the values obtained are probably too small, as the maximum force is certainly directed towards the left of our section.[1] We have also seen that the surface-current of this sea, carrying the true polar water, is about 200 m. thick,[2] and that its velocity near the surface varies from about 0·5 nautical mile in 24 hours north of Siberia, to 1·0 mile north of Spitsbergen.

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[1] A calculation of the force of circulation of the upper 200 m. of the sea between our Stat. 23 and the region southeast of the Franz Josef Archipelago would probably give a value twice or three times as great as that found between the same station and Arshenius's Stat. IV west of Spitsbergen (see p. 355). According to some observations made by Admiral Makaroff in the summer of 1901, I find the acceleration due to the force of circulation between our Stat. 23 and a place in 80° 26′ N. Lat., 64° 14′ E. Long. to be about 0·00018.

[2] The very cold under-current carrying the absolute minimum of temperature (cf. pp. 323, 390) may in this connection be considered as a part of the surface-current, as its waters are naturally carried out of the North Polar Basin along with that current.

The isopyknals of the warm under-current below 200 m., running in a direction more or less opposite to that of the surface-current, are situated almost horizontally; and we can get no idea of the forces producing this current simply by considering the course of the isopyknals. There are, according to my view, two chief causes of this current. (1) On the one hand it is a *current of compensation* for the sea-water carried out of the Basin by the Polar Surface-Current. The latter current is chiefly composed of river-water mixed with sea-water, and if we could calculate how much salt was daily carried along by the upper current, it would be easy to calculate how much of the sea-water of the under current would be required daily to compensate for this amount of salt.

(2) On the other hand, the under-current is evidently also a *convection current.* We have seen above that the water of this current is cooled down, and becomes heavier during its circulation through the Basin. The heavy bottom-water thus formed, is prevented by the probable sub-oceanic ridge (see later) between Spitsbergen and Greenland from running out, and must fill the deeper parts of the Basin. But if it were not, to some extent, carried out again, the Basin would soon be entirely filled with this heavy water underneath the polar surface-layer, and as the cooled water situated higher than the upper level of the ridge, would then be heavier than the warmer Gulf Stream water west of Spitsbergen, a circulation must arise, even if no part of the heavier water were carried out by the lighter surface-current. Owing to the deflecting force arising from the Earth's rotation, the heavy water would not flow out over the ridge under the warmer upper current near Spitsbergen, but would be deflected towards the right, and would flow out over the sub-oceanic ridge nearer Greenland. More warm water would run into the Basin near Spitsbergen to compensate for the outflowing heavy water, and thus a convectional circulation would be caused. As the out-flowing water will be forced towards the surface by the ridge, it is probable that it will be more or less intermixed with the less saline surface-water, and thus it may perhaps be explained why we find no bottom-water in the Norwegian Sea similar to that of the North Polar Basin.

The warm under-current is thus partly caused by the surface-current, partly by the cooling process. But the cooling process is evidently much retarded by the overlying stratum, 200 m. thick, of lighter water; and its effect upon the circulation is evidently much reduced by the sub-oceanic ridge

between Spitsbergen and Greenland. It is therefore probable that the former cause is of most importance. The surface drift-current is, however, caused chiefly by the force of circulation, and also to some smaller extent by the prevailing wind; and we thus see that the warm under-current is to some extent caused by the combined effect of these two forces.[1]

We may perhaps get some idea of the velocity of the warm under-current by comparing its thickness with that of the surface-current. If we assume that the surface-current is 200 m. thick, and has been mixed with a layer of river-water, so that the layer of original sea-water of 35·2 ‰ salininity carried out by this current is about 190 m. thick, and if we further assume that the warm under-current supplying compensation for this quantity is about 600 m. thick, we find that the mean velocity of the under-current must be $\frac{190}{600}$ or about 1/3 of that of the surface-current, provided that they have the same width. One source of error in this calculation would, however, be that the surface-current carries the greater part of its river-water in the uppermost layers, and these run with the greatest velocity. It is at present hardly possible to calculate what the mean velocity of the surface-current running out may be, as we know only the velocity near the surface, and that only in a small portion of the Basin. But if we assume the mean velocity of the surface-current to be 0·6 nautical mile in 24 hours, the mean velocity of the warm under-current would be about 0·2 naut. mile in 24 hours according to what has been said above. The velocity may however be considerably greater, as the outward-flowing surface-current is probably much broader than the warm under-current, and moreover, the under-current, as we have seen, probably has to furnish compensation for more than this surface-current.

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[1] If, in the enclosed North Polar Basin, the prevailing winds of the year blow from the inner end of this great fjord, near Bering Strait, towards its outlet between Spitsbergen and Greenland, they will on the one hand cause a surface-current flowing in this direction, with a deviation towards the right, as great as the coasts allow; but on the other hand they will as certainly cause a corresponding under-current running in the opposite direction to replace the surface-water carried away. This under-current must be formed, even if the water of the Basin had a perfectly homogeneous density. Owing to the Earth's rotation, the surface-water will naturally run out over the western end of the supposed ridge between Spitsbergen and Greenland, while the water replacing it will have a tendency to run in over the eastern end of the same ridge, west of Spitsbergen.

The effect of the winds will thus in this respect be similar to that of the force of circulation; but the depth of the outward-flowing wind-current will naturally to a great extent be limited by the downward increase of the density.

g. *Seasonal Changes in the North Polar Current.*

Our observations prove that there are seasonal changes in the surface drift-current of the North Polar Basin. This is what *a priori* might have been expected.[1] Owing to the continual loss of heat by radiation during the dark season, the atmosphere is much cooled down[2] over the north polar regions during the winter; it contracts considerably, and its upper-boundary forms a kind of depression over the centre of the cooled area. The result will be a very active convectional movement of the atmosphere; radiating, outward-flowing air-currents will be formed at the bottom of the atmosphere, along the Earth's surface, and converging in-flowing currents in its upper regions.[3] As a land surface is cooled down considerably more than the surface of the sea by the radiation of heat during the winter, and as there are extensive continental land-masses on both sides of the North Polar Basin, the centre of the cooled region will be a limited area, or rather a belt—Supan's 'Windscheide', (wind-shed)—extending across the North Polar Basin between the continents, with its heaviest part towards the cold pole of Siberia. This belt is probably situated nearer to the side of Bering Strait than to the Norwegian Sea or Barents Sea, which are warmed and kept open by the Gulf Stream. The result of this convectional movement of the atmosphere will naturally be that during and towards the end of the winter, there will be a comparatively active discharge of ice and surface-water from the North Polar Basin, especially towards the Norwegian Sea (or East Greenland Sea), and to some small extent also towards Bering Sea, where, however, the land is in the way.

During the arctic summer, the conditions will to some extent be reversed, and a considerable cooling and contraction of the atmosphere will take place over the antarctic region; thus leading to a shifting of the centre of gravity of the atmosphere towards this quarter. There will consequently be a tendency to southward air-currents in the upper regions of the atmosphere, and northward currents near the surface of the Earth. This move-

[1] Cf. A. Supan, 'Die arktischen Windscheide' etc., Petermann's Mitteilungen, 1891, p. 191.

[2] This cooling is to some extent checked by the condensation of moisture in the atmosphere and by the freezing of the sea, rivers, etc.

[3] This movement is increased by the circumstance that simultaneously the conditions are reversed in the south polar regions, which are being heated by perpetual sunshine.

ment will, however, be greatly checked by the continual loss of heat engaged by the melting of ice and snow in the north polar region, but a pause in the northerly winds, together with more irregularity, must nevertheless be produced during the summer. We have thus a very feasible explanation of the seasonal changes in the drift of the ice and in the North Polar Surface-Current along the east Greenland coast.

We might expect that there would be seasonal changes in the convection currents of the North Polar Sea similar to those of the atmosphere; but the changes thus produced will not be of much importance, for, as has been pointed out (see p. 314), the loss of heat by emission during the winter, does not cause perceptible seasonal changes in the temperature of the water deeper than 40 m. from the surface, at the most, and even at 20 m. the seasonal changes are very inconsiderable. The cooling has much more tendency to produce a regular, permanent circulation.

According to what has been stated above, we may expect that, just as the convection currents of the atmosphere cause an increased activity of the North Polar surface-current during the winter, so they will, in connection with the heating of the open sea-surface, produce an increased activity of the surface-current of the Gulf Stream during the summer; and we perhaps thus have the chief explanation of these great seasonal changes.

The seasonal changes in the convectional movement in the sea, caused by the increased cooling during the winter, might have a tendency to check the above periods, as the increased sinking of cold water will help to increase the influx of warm water from the south during the winter. But even in the Norwegian Sea the vertical distribution of the density prevents, to a great extent, the yearly range of temperature from reaching any considerable depth, and the seasonal changes of the currents thus produced will not be of much importance, the effects of the increased cooling during the winter being to some extent distributed over the whole year.[1] The effect of the cooling of the surface-layers of the Gulf Stream may, however, be that in becoming heavier they will sink somewhat, and are then very naturally replaced more or less by the less saline, and lighter polar water from the north.

[1] It ought to be remembered that the surface-waters of the Gulf Stream are also cooled down in the southern parts of the Norwegian Sea during the winter, and that the cooling produces there perhaps a still greater change in the density, as the temperature is originally higher.

It may thus have a tendency to increase the polar surface-current towards the end of the winter, and to give the polar surface-waters a wider southward extension; making the surface of the Norwegian Sea less saline.

In a somewhat different manner the cooling during the winter of the surface-water of the Gulf Stream may, have a still greater apparent effect. The waters of the Gulf Stream flowing north-east and northward, more or less parallel to the coasts of Norway and Spitsbergen, are lighter than the underlying water and the water to its left, *i. e.* to the west. The upper layers of the Gulf Stream water have consequently a strong tendency to spread over the heavier surface-water towards the west; but this tendency is counterbalanced by the deflecting force of the moving water, arising from the Earth's rotation. A lateral equilibrium is attained when these two forces (the tendency to spread westward, and the deflecting force acting in an easterly direction perpendicular to that of the current) are exactly equal (cf. what is said about this in the next section, h). But if it be assumed that equilibrium in this respect be attained at the end of the summer, and if the current continues to flow with the same velocity during the winter, it is clear that the cooling of the surface-waters of the current during the winter will disturb the equilibrium, as it gives the surface-waters a higher density, and consequently reduces their tendency to spread westward, while the deflecting force remains the same. The result must be an eastward motion of the colder surface-waters to the west of the Gulf Stream, and the latter will, at the end of the winter, be covered with colder water more or less mixed with polar water coming from the west. During the summer the surface-waters of the Gulf Stream are again heated and made lighter; their tendency to spread westward is increased, and, if lateral equilibrium has been attained at the end of the winter, this will necessarily result in a westward motion of the surface-waters of the Gulf Stream during the summer. This motion may also be somewhat increased by the greater addition of land-water during the spring, owing to the melting of the snow and ice on land.

We shall eonsequently see, that, not considering the winds, there would be a motion of the surface-layers of the Gulf Stream water from the coasts of Norway and Spitsbergen during the summer—*i. e, the surface-current will become broader during the summer*—and a motion in the opposite direction towards the coasts during the winter, *i. e. the surface-current will become*

narrower during the winter and will gradually be covered with colder water coming from the west. This seems to agree well with the observations hitherto made (especially by Dr. *Johan Hjort*) at the various seasons of the year.

h. *The Conditions in the Still Unknown Portion of the North Polar Basin.*

This point has already to some extent been discussed above (cf. pp. 337 *et seq.*). We certainly cannot expect to find that the conditions observed along the Fram's track, prevail over the whole of this basin. Some of our observations at various stations even indicate that there were differences between the conditions found nearer the southern edge of the deep basin, and those farther away from it. As we have seen above, it is natural that, owing to the deflecting force arising from the Earth's rotation, the warm undercurrent should follow close along this edge of the continental shelf, while on the other hand the cold surface-current running in the opposite direction should have a strong tendency to deviate towards the right, *i. e.* northward, a tendency which is, however, checked by the resistance from the coasts on the America-Greenland side.

The Polar Surface Current must consequently be expected to be thickest towards the latter side, provided that the configuration of the coasts on that side does not reduce the rate of the current too much. If we assume that the mean surface-velocity of the whole current be 0·73 mile in 24 hours, or 1·565 cm. per second, and that its mean Latitude be 86° N., we find that the acceleration due to the deflecting force of this current should be $= 2\ \omega\ 1{\cdot}565 \times \sin 86° = 0{\cdot}0002277$.

As this force acts upon every cubic centimetre of the surface-water we have simply to mutiply it by the density and the breadth of the current, expressed in centimetres, and divide the product by the acceleration of gravity, to find the pressure which the deflecting force will exert upon every square centimetre of the underlying water-strata on the right side of the current, if the deflected water be pressed up against land. Let us assume, that the mean density of a vertical water-column from the surface to the bottom of the current be the same everywhere along a transverse section,[1] *e. g.* 1·02694

[1] On the right side of the current we may expect each stratum of low density to be thicker than on its left side, but as its whole thickness may be correspondingly increased, the mean density may nevertheless remain the same.

(which is the mean density at Stat. 23), that the bottom-water underlying the current has no motion, and that its mean density be nearly uniform and about 1·02800. Let us furthermore assume the depth of the current on the left side, near the edge of the Siberian continental platform, to be 140 m. (at Stats. 20 and 22 it was probably about 170 m.), and its breadth to be 1110 kilometres. We then find that the surface-current must be about 390 m. thick on its right side, near the edge of the America-Greenland continental platform, if lateral equilibrium is to be established and the pressure arising from the deflecting force is to be counterbalanced by the reduction of the pressure arising from the greater thickness of the surface-water with lower density. If the current have only half the breadth (555 kilometres), its depth on the right side would be about 265 m.

With a mean velocity of 0·73 mile in 24 hours and a uniform mean density across its breadth, the thickness of the Polar Surface-Current would consequently increase 0·225 m. for every kilometre, or 1 m. for every 4·44 kilometres of its width, measured transversely to its direction. On the one hand the mean surface-velocity in a transverse section is probably greater, and if so, the increase of the thickness will also be greater; but on the other hand it is doubtful whether the mean densities of the vertical water-columns from the surface to the bottom of the current, are uniform along a transverse section. Our observations may indicate the possibility that near the New Siberian Islands at least, the mean density of the current is lowest on its left side near the Siberian coast, whence it receives the greatest addition of fresh water. If this were a general rule, it would naturally tend to increase the difference of thickness on both sides of the current; but it would also tend to change the direction of the current, and it is therefore probable that on the whole the conditions are reversed,[1] and off the East Greenland coast the mean density of the current seems to be lowest on its right side near the coast. If so the increase of thickness towards the right side of the current will be correspondingly diminished. We have assumed above that the underlying water is at rest. This is, however, not the case, as the water under

[1] The observations of the Vega-expedition seem for instance to indicate that the densities of the sea-water between 10 m. and 100 m. were higher near Cape Chelyuskin and north of the Eastern Taimur Peninsula than at our Stations in the North Polar Basin. See O. Pettersson, Vega-Exped. Vet. Iakttagelser, vol. II, pp. 357, 365; Pl. 24, Section V, Pl. 26, Section VI. See also above p. 289.

the left side of the surface-current runs more or less in an opposite direction, and owing to the deflecting force, this will tend to increase the inclination of the lower boundary of the overlying surface-current in a transverse section. The configuration of the unknown edge of the basin on the right side of the current will naturally also be of importance in this respect. It is clear, for instance, that if the current is blocked up, say on its right side, by the northern extremity of Greenland, which suddenly narrows the outlet of the large fjord-like basin, its velocity may be much reduced on that side, north-west of Greenland or north of the American Arctic Archipelago. Moreover the under-current probably runs in a similar direction to the surface-current, and the thickness of the latter will therefore not increase so much towards that side as the above calculations indicate, and may even decrease towards land; for as moving water will carry along with it water with less motion, the more rapid current will, as it were, suck away the water of the less rapid current at the sides, and thus the current has naturally a tendency to be thickest where its velocity is greatest. The sub-oceanic ridge between Spitsbergen and Greenland may have a similar effect, especially if it be very shallow towards the side of the latter.

If, however, the results of the above calculations be correct, to some extent, we shall see, for instance, that a difference of about 30 m. in the depth of the lower boundary of the surface-current, such as we have found between Stats. 22 and 23, and Stat. 24, may indicate that the latter station was situated 133 kilometres farther from the southern edge of the current. This result does not seem very improbable; for if we draw two lines in the direction of the current, one through Stats. 22 and 23, and the other through Stat. 24, the distance between these two nearly parallel lines will be about 80 miles or 148 kilometres.

From what has been said above, we may expect that, on the whole, the isopyknals of the Polar surface-current incline towards the Greenland-American side in a transverse section of the current, or rather they may incline towards the axis of the current, where this has its greatest velocity.

The *warm under-current* must be expected to be thickest and most developed near the Eurasian continental slope (cf. p. 334), and that stratum of the current which runs with the greatest velocity will in that direction become relatively as much thicker than the rest, as its deflecting force is greater. It is pro-

bable that the velocity and thickness of the whole current is greatest at some distance from the right side of the basin, as the increased friction and resistance will reduce the velocity near the continental slope. This may to some extent be the reason why the bottom-water of the North Polar Basin as well as that of the Norwegian Sea will rise towards the coasts.[1]

The intermediate strata of the warm current, with the highest temperatures, have probably the greatest velocity, for the rate at which the water flows near its upper boundary is much reduced by the friction against the overlying water running in a different direction; and on the other hand, the very deep strata naturally run very slowly.

A great part of the water of this current is gradually mixed with the waters of the surface-current, and is again carried out of the Basin with the latter. It consequently seems probable that the volume, or the rate, of this warmer current is much reduced during its circuit along the edge of the North Polar Basin, and on the Greenland-American side we must expect the current to be smaller, less rapid, and with lower temperatures than on the Siberian side. Owing to the deflecting force arising from the Earth's rotation, and also owing to the centrifugal force, the waters of this circulating current will be pressed against the continental slope, forming the sides of the deep Basin, and this will produce an accumulation on the right side, and consequently a pressure on the underlying water-strata. This pressure, which is greatest on the Siberian side, where the current is most developed, must be counterbalanced by the rising of the colder and heavier bottom-water of the Basin towards the surface in its central portion.

If we assume the mean velocity of the current on the Siberian side to be 0·2 nautical mile in 24 hours, or 0·4287 cm. per second, we find that the acceleration due to the deflecting force arising from the Earth's rotation would be $2\,\omega \times 0{\cdot}4287 \times \sin 83^\circ = 0{\cdot}00006206$. Let us assume that the central portion of the Basin, where the heavier bottom-water rises towards the surface, has its centre somewhere near the Pole (nearer to the Greenland-American edge of the basin than to the Eurasian side), and that the distance from this centre to the right side (the Eurasian side) of the warm under-current is 7° of latitude, or 777 kilometres.

[1] The moving bottom-water will naturally also have a tendency to follow the configuration of the bottom (cf. p. 336).

From what has been said above, we might expect that the overlying Polar surface-current would be perhaps 170 m. thicker at this place, than near the Eurasian side of the Basin. The upper 170 m. of the water of the right side of the warm under-current will thus be counterbalanced by the difference in density between it and the overlying surface-current running in the opposite direction. If the warm under-current be about 710 m. thick on its right side (filling the interval between 140 m. and 850 m. of depth), we find that between the mean vertical density of the lower 540 m. of water on the right side of the current, and that of the corresponding water-column in the same level in the above-mentioned centre with heavier water, a difference of 0·00008 would be necessary to counterbalance the pressure exercised by the deflecting force of the warm current on the underlying strata of bottom-water. If the salinity be the same in both water-columns (which is hardly correct) and the mean temperature of the warm water-column be 0·7° C. we find that the mean temperature of the water-column in the central portion of the Basin must be about —0·7°,[1] which does not seem to be improbable, as we have found this temperature at about 1800 m. along the Fram's track (cf. p. 307). It may be, however, that the salinity of the bottom-water pressed up in the central portion is somewhat greater than that of the warm current, and if so, the difference of temperature will naturally be correspondingly less. If the mean velocity of the warm current be smaller, or its width be reduced, the above difference of density or temperature will naturally also be reduced accordingly.

In the region near Spitsbergen and Greenland, the North Polar Basin is probably much narrower than nearer the Pole, and we must consequently expect the velocity of the surface-current, and perhaps also that of the warm under-current, to be greater,[2] and in a transverse section across this part of the Basin we must expect the thickness of the water of the surface-current to increase more rapidly towards the west, and its thickness on the left side to diminish more than is the case nearer the inner portion of the Basin. Near Spitsbergen the surface-current has even disappeared more or less, and moved towards the Greenland side.

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[1] The density of sea-water of 0·7° C. and 35·25 $^0/_{00}$ is 1·02815, and that of sea-water of —0·7° C. and 35·25 $^0/_{00}$ is 1·02823.

[2] The greatest velocity of the surface-current was observed during the last part of the Fram's drift (1 mile in 24 hours).

On Pl. XXIX I have attempted to construct a hypothetical section—such as I think ought to represent the facts, according to what has been said above—across the North Polar Basin, from a point somewhere between the Franz Josef Archipelago and Cape Chelyuskin, to a point near the western end of Grinnell Land (see Pl. I, Section X).

The surface-layer of the true Polar Water, with low salinity and low temperature, is, in this section, 140 m. thick near the Siberian continental slope; the thickness increases to about 300 m. where the surface-current may have its greatest velocity, and than decreases again towards the American side. The warm under-current, with temperatures above 0° C. is situated on the Siberian side of the section. The continuation of this under-current is also traceable on the American side, but its volume is considerably reduced, and its temperature is reduced below 0° C. (cf. p. 338). Here it is also less distinctly separated from the overlying polar surface-current, with the waters of which it is more intermixed. In the middle of the North Polar Basin, the colder bottom-water with a relatively high salinity and density, will rise higher than under the warmer circulating current on both sides, and near the middle of the basin, towards the American side, will probably approach the surface-layer of true Polar Water. That the conditions actually must be so, if there is to be equilibrium, is simply a necessary consequence of what has been said above. It will also be seen that a hypothetical section of the North Polar Basin thus constructed, has a great resemblance to the Sections (Pls. XXX, XXXI) across the northern part of the Norwegian Sea from Bear Island and Spitsbergen to Greenland, which I have constructed from the results of the latest researches (see later).

The ice-drift. I have said above that there was a probability that the velocity of the westward polar surface-current or surface-drift increases northward from the Eurasian coast, in the North Polar Basin. This may explain why the relics from the Jeanette evidently travelled across the polar sea with a much greater mean velocity than the Fram. The Fram needed about 34 months to drift about 1028 miles in a straight line across the North Polar Basin (*i. e.* a mean daily drift of 1·068 nautical miles), while the relics from the Jeanette drifted nearly three times that distance or about 2900 miles, in 36 months, which gives a mean daily drift of 2·6 nautical miles. Although the velocity of the current along the Greenland coast is much greater than

in the North Polar Basin, it seems evident that the floe with the relics cannot at any rate have taken more than two years to cross that basin; and it must there at least have travelled with a mean velocity of 2 miles in 24 hours,[1] while the mean velocity of the ice-drift near the Fram, when measured in a straight line, was only 1·068 miles in 24 hours. The mean velocity of the whole drift of the Jeanette, measured along a straight line was 0·93 mile in 24 hours, or very similar to the Fram; but the last year, from January 1st to June 16th, 1881, she drifted with a mean daily velocity of 2·46 miles.[2] It is evident that the ice in that region travelled at a considerably quicker rate than the ice round the Fram along the greater part of her track; for it was only during the last year that she travelled as much as 1·5 miles daily.

The Jeanette relics have evidently travelled along a track parallel to that of the Fram.[3] During Johansen's and my sledge-journey, we actually believed we found more motion in the ice the farther north we came. In some places great lanes were formed; and in some parts far north the ice was very uneven and much broken by pressure, and was in active motion. Our astronomical observations also indicate that we had much westward drift, near our farthest North, in the beginning of April, 1895.

The reason why the westward drift is more rapid towards the north, is evidently that we there come nearer to the axis of the surface-current, where it runs at a greater rate. This may also to some extent be the reason why we found the permanent surface-current to be strongest during the last year of the Fram's drift (but see also p. 403).

According to what has been said, it is probable that an expedition which entered the drifting ice north or north-east of Bering Strait would be carried much farther north than the Fram, and would travel with a greater mean velocity; but the distances which would have to be traversed would naturally be much greater.

Beyond a certain latitude we must expect the surface-drift to decrease in velocity towards the American side. The current and the ice-drift will evidently be blocked up against the north coasts of Greenland and the American Arctic Archipelago, and as only a small portion of this blocked-up

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[1] Cf. Nansen, 'Plan til en ny polarekspedition', Naturen, Bergen, 1890, p. 72; and *ibid.* 'How can the North Polar Region be crossed?' Geographical Journal. vol. I, 1893, p. 20.

[2] The mean daily rate during the first part of the Jeanette's drift, from Sept. 9, 1879, to Jan. 1, 1881, was 0·397 mile, measured along a straight line.

[3] Cf. Nansen, Geograph. Journal. vol. I, 1893, map; and also Naturen, Bergen, 1890, map.

ice-drift escapes through Smith Sound and the sounds between the American islands, it is possible that some small portion of the ice deviates towards the right, and forms a kind of eddy or a more or less complete circumpolar ice-drift moving in the opposite direction to the circumpolar warm under-current.

i. *The Oceanographical Conditions of the North Polar Basin compared with those of the Norwegian Sea.*

In order to form a more complete idea of the circulation of the northern seas, it now remains to compare the waters of the North Polar Basin with those of the Norwegian Sea.

The bottom-water of the North Polar Basin is distinctly different from the bottom-water of the Norwegian Sea, which is colder and has a considerably lower salinity. According to our observations on board the Michael Sars in 1900,[1] the bottom-water is remarkably homogeneous in the whole of the latter basin; the salinity of the water below 1000 m. hardly varies as much as 0·01 ‰, and the temperature is relatively low. The temperature, at depths near the bottom, between Norway and Iceland or Jan Mayen, is below —1° C., (at 3000 m. between —1·1° C. and —1·2° C.), and the salinity is 35·06 ‰.[2] Thus the density is nearly uniform, about 1·02808.

In the northern part of the Norwegian Sea between Spitsbergen and Greenland, the salinity seems to be exactly the same, but the temperature is still lower, probably about —1·3° C. and —1·4° C., while the lowest temperature of the bottom-water of the North Polar Basin, according to our observations, was about —0·87° C., with a salinity of 35·29 ‰, which gives a density of about 1·02825.

If there were an open communication between the North Polar Basin and the deep basins of the Norwegian Sea, the latter would necessarily be filled with the bottom-water from the north, which is so much heavier, the bottom-water of the Norwegian Sea having a density of only 1·02808. *We are therefore obliged to assume that the basin of the Norwegian Sea is*

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[1] See Nansen, Nyt Mag. for Naturv. vol. 39, Christiania, 1901, pp. 149 *et seq.*

[2] This salinity should perhaps more correctly be 35·08 ‰ or 35·09 ‰, if calculated in the same manner as the salinities of the present Memoir.

separated from the North Polar Basin by a comparatively shallow sub-oceanic ridge (or plateau) uniting Spitsbergen with Greenland. This ridge probably forms a continuation of the ridge extending towards the north-west, from the north-west corner of Spitsbergen, where it is between 475 m. and 786 m. deep. Towards the Greenland side it is probably shallower.

This ridge is to a great extent the cause of the great slowness of the circulation in the depths of the North Polar Basin. If the ridge were made lower or taken away, the result would be that there would be very nearly the same bottom-water in the Norwegian Sea as in the North Polar Basin; it would become warmer and more saline in the former, but colder in the latter. If the Scotland-Færoe-Iceland ridge were also removed, the whole circulation of the northern seas would be much increased; there would be a comparatively active outflow of cold water along the bottom into the Atlantic Ocean, and a much more active influx of warm water into the Polar Basin.

The North Polar Surface Current. The East Greenland Polar Current is evidently the direct continuation of the Surface Current of the North Polar Basin observed during our expedition, but the greater volume of the water of the former comes probably from the regions to the north of the Fram's track (cf. the section Pl. XXIX). In July, 1891, Capt. *C. Ryder*,[1] on board the Hekla, made a very interesting section across the Polar Current east of Greenland, between Lat. 74° and 76° N.,[2] which gives valuable information especially as to vertical distribution of temperature. Unfortunately the salinities or specific gravities obtained do not appear to be sufficiently accurate.[3]

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[1] 'Meddelelser om Grønland', vol. 17, Copenhagen, 1895, pp. 191 *et seq.*

[2] See Pl. I, Stats. IX–XIV.

[3] The Sigsbee Water-Bottle used for collecting samples from the water-strata deeper than 150 fathoms, had evidently not closed tightly, and the enclosed samples have been mixed with water from the upper, less saline strata of the sea during hauling up. For depths between the surface and 150 fathoms, a Rung's Water-Bottle was used, and the salinities obtained make it probable that this instrument worked more satisfactorily, but even for these depths there are evidently considerable errors in the salinities. Mr. *K. Rørdam*, who has determined the specific gravity $\left(S\frac{15^\circ\text{C.}}{15^\circ\text{C}}\right)$ of Ryder's samples with a bottle pyknometer has made a strange mistake in using the factor 1295·6 for converting the values of $\left(S\frac{15^\circ\text{C.}}{15^\circ\text{C.}}\right)$ to salinity (Medd. om Grønland, vol. 17, p. 229). His correct factor would have been about 1307. The salinities obtained by this factor do not, however, agree with those obtained by his titrations, which are much too low, and it proves that his determinations on the

A number of highly valuable series of temperatures and water-samples were taken in the summer of 1901 by Capt. *Roald Amundsen* in the sea north of Jan Mayen, (see Pl. I, A 13—A 23). These observations, which I am going to describe in a later paper, give us for the first time really trustworthy information regarding this part of the current, but unfortunately the pack-ice prevented Amundsen, in his small vessel, from continuing his section straight across the current to the east coast of Greenland.

During the *Kolthoff* Expedition on board the Frithjof, in July, 1900, two interesting series of temperatures and water-samples, were taken by Mr.

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whole are unsatisfactory. But even if we take Rørdam's highest values of salinity, correctly calculated from his specific gravities $\left(S\frac{15^\circ C.}{15^\circ C.}\right)$, they are as a rule much too low for the samples from greater depths. From our investigations on board the Michael Sars in 1900, and from Capt. Amundsen's water-samples from the East Greenland Sea, we now know that below a certain depth the salinity of the water-strata of the Norwegian Sea and the East Greenland Sea, both north and south of Jan Mayen, is nearly uniform (about 35·06 $^0/_{00}$, in some places perhaps a little more), and this affords an excellent opportunity to control the results of previous expeditions. We may thus be certain that the salinity for depths greater than 1000 m. at Ryder's Stations was about 35·06 $^0/_{00}$, but Mr. Rördam's pyknometer determinations of Ryder's samples, correctly calculated, give the following salinities:

Stations	Depth in Metres	Salinity	Error	Stations	Depth in Metres	Salinity	Error
I	1100	35·24 $^0/_{00}$	−0·18 $^0/_{00}$	IX	915	34·87 $^0/_{00}$	+0·19 $^0/_{00}$
—	1830	35·30	−0·24	—	1830	34·83	+0·23
II	1280	35·20 (?)	−0·14	X	1100	34·93	+0·13
III	1280	34·94	+0·12	XI	1830	34·47	+0·59
IV	1830	35·01	+0·05	XII	1830	34·79	+0·27
VIII	915	34·52	+0·54				
—	1830	34·73	+0·33				

We see that the errors are so great and so irregular, that the results obtained are valueless. The water-bottle has probably been very defective. But the determinations of the water-samples from the upper water-strata evidently also give, to a great extent, erroneous results. Thus the corrected salinities obtained for the warm undercurrent at Stats. XII and XIII are evidently much too high, for our investigations on board the Michael Sars in 1900 have taught us that the density of an overlying water-stratum is as a rule no greater than that of an underlying stratum in the sea. The salinities for similar depths of the cold current are, however, more probable. There is thus no rule, and therefore no certain conclusions can be drawn from Ryder's investigations in this respect. The determinations of the sea-temperature seem, however, to be more trustworthy. Ryder states that his Negretti and Zambra reversing thermometers had been tested at Kew, but unfortunately says nothing about their corrections, or whether the temperatures given have been corrected.

Östergren in 77° 11′ N. Lat., 0° 55′ W. Long., and in 72° 10′ N. Lat., 10° 57′ W. Long. (Pl. I, Stats. F_1, F_2).[1]

From the observations of *Amundsen* in 1901 (Stations 15, 13, 20, 23, and 19), *Ryder* in 1891 (Stats. XI—XIV), and Dr. *Hjort* on board the Michael Sars in 1900[2] (Stats. 62—64), I have made an attempt to construct a transverse Section across the Norwegian Sea from Bear Island to Greenland, showing the vertical distribution of temperature and salinity (Pl. XXXI).[3] I have also constructed a similar section (Pl. XXX) from Spitsbergen to Greenland, using the observations of Prof. *Arrhenius* in 1896 (Stats. I—VI), Östergren on board the Frithjof in 1900 (Stat. F_1), and *Ryder* in 1891 (Stats. IX—XIV).

Although these sections are to some extent inaccurate, especially at Ryder's stations near the Greenland coast, and also because the observations are taken in different years, they give a fairly correct idea of the general conditions of the East Greenland Polar Current.

We see that the Polar Current has become very much narrower along the East Greenland coast than it evidently is in the North Polar Basin. Its depth is also on the whole very much less, but it increases rapidly eastward and near the Greenland coast, and at Ryder's Stat. XIII it is very nearly the same (200 m.) as it was at our Stats. 24—26.[4] On the other hand, it evidently runs with a much greater velocity along the northern East Greenland coast than in the North Polar Basin, its velocity being at least double that observed near our Stat. 26; and thus it carries a greater volume of water than might appear from the much reduced area of its transverse section. This increased velocity is also, as before mentioned, the reason why the depth of the current increases so rapidly eastward, and to some extent

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[1] O. Pettersson and Hj. Östergren, Ymer, vol. XX, Stockholm, 1900, p. 326. The temperatures from the deeper water-strata at these stations are evidently too high, as the water-bottle has not been sufficiently insulating. The water-sample from 2000 m. at Stat. II is evidently erroneous; the water-bottle has probably been closed at about 100 m.

[2] Cf. Nansen, 'Some Oceanographical Results', etc.

[3] Ryder's salinities of the warm under-current have been reduced to the maximum value that they possibly may have possessed, and I give only one decimal place of permillage. The salinity of Ryder's bottom-water has also been corrected to the probable value.

[4] The thickness of the current is, however, much smaller than the probable maximum thickness (see p. 404) of the surface-current in the North Polar Basin. The thickness of this current is evidently much reduced where it has to pass the sub-oceanic ridge between Spitsbergen and Greenland, as its lower boundary is lifted towards the surface by the pressure of the underlying water on the north side of the ridge.

also why its width is so much reduced. The East Greenland Polar Current evidently forms the chief outlet of the Surface Current of the North Polar Basin. Let us assume that the width of the Polar Surface Current along our hypothetical section across the North Polar Basin be 1100 kilometres, its mean thickness 200 m., and its mean velocity 0·73 mile or 1·35 kilometres in 24 hours. We see then that this current carries about 297 cubic kilometres every 24 hours. Let us similarly assume that in our section from Bear Island to Greenland the width of the East Greenland Polar Current be 800 kilometres, its mean depth 90 m., and its mean velocity 2 miles or 3·7 kilometres in 24 hours. This current would then carry about 266 cubic kilometres every 24 hours. These volumes are probably too great in both cases, as the above velocities may be the mean surface-velocities, and not those of the whole thickness of the current; but the relative errors thus obtained will probably be nearly the same in both cases.

That the East Greenland Polar Current is no deeper on its right side, is evidently to some extent caused by the shallowness of the sea near the Greenland coast; and the Spitsbergen-Greenland Ridge to the north is probably also very shallow on that side (see p. 413, and foot-note 4, p. 409).

North of Iceland the Polar Current meets much resistance. The sea along the Greenland coast suddenly becomes shallower at the sub-oceanic ridge across Denmark Strait from Iceland to Greenland, and in another place I have pointed out what a remarkable influence the form of the bottom has even on surface-currents.[1] The Polar Current is therefore blocked up by this ridge, as well as by Iceland itself, and also to a considerable extent by the warm Irminger Current running north over the ridge west of Iceland. The result is that the Polar Current is divided into two branches; one comparatively narrow branch finds its way over the western end of the ridge, and runs south-west close along the Greenland coast with a comparatively great velocity,[2] while the other and probably greater branch is compelled to find its outlet between Jan Mayen and Iceland, forming the East Icelandic Polar Current. It is, however, remarkable how very similar the depth and the vertical distribution of temperature and salinity of these two branches are

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[1] Cf. pp. 260 *et seq.*, 333 foot-note; and also Nyt Mag. for Naturv., vol. 39, pp. 152 & 153.

[2] In July, 1888, we found the surface-velocity of this current to be about 24 nautical miles in 24 hours (see H. Mohn and F. Nansen, Petermann's Mitteilungen, Ergänzungsheft No. 105, 1892, pp. 52, 101).

to those of the Surface Current of the North Polar Basin. This may, for instance, be distinctly seen if the observations at Stations 13 and 18 of the Michael Sars in 1900, be compared with ours from the North Polar Basin. Stat. 13 was situated in Denmark Strait in 66° 42′ N. Lat. and 26° 40′ W. Long. Pl XXXIII, Section XIV represents a section from our Stat. 26 (Lat. 84° 6′ N.; Long. 12° 26′ E.) through Ryder's Stats. XIII and XXVII, to Stat. 13. The forms of the isotherms of the lowest temperatures, —1·75° C., —1·5° C., and —1° C., demonstrate how the Polar water is gradually but slowly heated during its southward course. We see that the minimum temperatures are situated much in the same depth as in the North Polar Basin, but somewhat deeper at the most southern Stations, especially at Stat. 13. The isotherm of 0° C. and the isohaline of 35 ‰, indicating approximately the lower boundary of the Polar Current, are also situated in much the same depth, about 200 m., but somewhat deeper at Stat. 13.

Stat. 18 of the Michael Sars is situated in the Polar Current between Iceland and Jan Mayen in 69° 9′ N. Lat., and 12° 0′ W. Long. Here we find a remarkably similar vertical distribution of temperature and salinity in the polar water,[1] only that the temperature has become higher, especially near the surface, the minimum, —1·42° C., being situated at about 60 m. The salinity is also higher. The isohaline of 35 ‰ is situated at about 180 m. and the isotherm of 0° C. at about 140 m. At Stat. 19 of the Michael Sars, 1900, the conditions are very nearly the same. Nearer Iceland, on the right side of the current, the surface-layer with salinities below 35 ‰ naturally becomes much thicker, attaining even 300 m. near Iceland; but the temperature becomes higher at the same time.

We thus see that the cold surface-layer, about 200 m. thick along the Fram's track, with low salinities, below 35 ‰, of the North Polar Basin can be traced as a continuous surface-layer—on the one side into the East Icelandic polar current, which carries it into the Norwegian Sea (to some small extent also into the Atlantic), where it is gradually lost by intermixture with the Gulf Stream water,—and on the other side into the Southern East Greenland Polar Current which carries it into the Atlantic. A portion of this current finally rounds Cape Farewell.

[1] Cf. Nansen, 'Nyt Mag. for Naturv.', vol. 39, Pl. 4, Fig. 7; Pl. 10, Section VI; and p. 155.

From what has been said above, it will be easily seen that the designation by previous authors of the cold and less saline water of the East Greenland and East Icelandic Polar Current as 'ice-water' or 'melting water', and their constant mention of it as if it were formed by the melting of the polar ice, are misleading. Prof. *Otto Pettersson* even calculated that the water of the East Icelandic Polar Current consists of 1/18 of water arising from ice-melting, intermixed with 17/18 Atlantic water.[1] We have seen that the water of the Polar Current covers the whole of the North Polar Basin, and arises chiefly from an intermixture of Atlantic water (to some small extent also Pacific water through Bering Strait) with river-water running into this sea, and also with the precipitation falling over the Polar Sea itself, where the evaporation from the ice-covered surface is relatively insignificant. The ice-melting is naturally of very little importance in this respect, for even though the greater part of the polar ice finally melts in the water of the Polar Current, it must be remembered that this ice was originally formed in the same water. Moreover, the light water produced by the melting will remain near the surface of the sea for some time, and would not at once be able to influence the salinity of the underlying sea-water down to depths of 100 or 150 m.

Prof. Otto Pettersson believes that the polar ice and the process of melting in southern latitudes is of great importance for the circulation of the ocean; and he thinks that the East Iceland Polar Current, running south-east into the Norwegian Sea, is chiefly produced by the melting process between Iceland and Jan Mayen. In another place[2] I have pointed out the chief mistakes made by Pettersson in forming this theory. Besides greatly over-rating the mean thickness of the ice, he has not been aware of the fact that the whole Polar Sea is covered with a thick layer of water, from 150 to 200 m. thick, with comparatively low density, and that the buoyancy of this layer produces a force of circulation which is the chief factor in forming the Polar Current. The buoyancy of the comparatively thin layer of ice, or of the corresponding layer of fresh water arising from its melting, is naturally of but little importance in comparison.

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[1] O. Pettersson, Petermanns Geogr. Mitteilungen, 1900. Parts III, IV. *Idem.*, Översigt K. Svenska Vet.-Akad. Förh., 1899, No. 3.

[2] Nyt Mag. for Naturv., vol. 39, p. 156.

The Warm Current. The under-current of warm water (at 0·4° C. and 0·6° C.) which Capt. Ryder discovered below the Polar Current off the east coast of Greenland (at his Stats. XII, XIII and XXVIII), is very interesting. I believed at first that this current might be a northward continuation of the Irminger Current west of Iceland; but since the sounding taken on board the Frithjof in 1900[1] in 77° 11′ N. Lat. and 0° 55′ W. Long. and the observations of Capt. *Amundsen* in 1901, I have arrived at the conclusion that this East Greenland warm under-current must be a branch of the Gulf Stream running northward west of Spitsbergen; and I think that this branch proves that the above-mentioned sub-oceanic Spitsbergen-Greenland ridge must be very shallow in the unknown region west of Long. 3° E., for otherwise the whole volume of warm water would be obliged to run into the North Polar Basin. It seems probable that when the Spitsbergen Gulf Stream meets the above-mentioned ridge, it is blocked up (cf. p. 334) in the same way as the Polar Current north of the Iceland-Greenland submarine ridge,[2] and is divided into two branches, *one branch* running westward along the southern slope of the ridge, and gradually sinking under the Polar Current, which it then follows southward along the Greenland east coast, *another and greater branch* passing over the ridge and forming the warm under-current of the North Polar Basin, observed by us. We may perhaps see an indication of this division in the section constructed through Arrhenius's Stations I—VI and Frithjof's Station (Pl. XXX). The warm saline water is actually less developed at Arrhenius's Stat. V than on both sides.[3]

Section XIII, Pl. XXXII is constructed through Stations 46, 67, 65, and 63 of the Michael Sars, 1900,[4] Arrhenius's Stat. IV, and our Stat. 26. In the summer of 1900, the Gulf Stream was evidently much less developed than usual in the sea west of Bear Island, and this, to some extent at least, is probably the reason why this current is comparatively so shallow at Stats. 67, 65, and 63; while its lower boundary (the isohaline of 35 ‰ and the

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[1] See Section on Pl. XXX, Stat. F_1.

[2] The Irminger Current is also divided in a similar manner south of the same ridge. See M. Knudsen, 'Hydrography', The Danish Ingolf Expedition, vol. I, No. 2, Copenhagen. 1899, p. 113.

[3] An indication of the same division into two maxima may perhaps even be seen in *Mohn's* temperature-sections, XXII and XXIII, across this current west of Spitsbergen farther south. See 'The North Ocean', The Norwegian North Atlantic Expedition, 1876—78, Pl. XIII.

[4] Cf. Nyt Mag. for Naturv., vol. 39, Pls. 1 and 8.

isotherm of 0° C.) again sinks abruptly towards Arrhenius's Stat. IV.[1] The section clearly demonstrates the difference between the Norwegian Sea and the North Polar Basin. In the former the warm Gulf Stream runs near the surface over a floor of cold and less saline bottom-water (of 35·06 ‰), while in the North Polar Basin it sinks below the lighter surface-layer of Polar water, and fills the whole basin below 200 m. with saline and relatively warm water.

It is, however, surprising that only at a single depth, *viz.* Stat. IV, 400 m., does the salinity of Arrhenius's water-samples reach the value of 35·29 ‰, which, according to my determinations, is the salinity of the bottom-water of the North Polar Basin (cf. p. 331). As mentioned on pp. 230 and 233, the Swedish determinations give on the whole somewhat lower values of the salinity than were obtained by our determinations at Christiania, and 0·06 ‰ or 0·08 ‰ has perhaps to be added in order to make them equivalent to ours. It may also be that the water-bottle used by Arrhenius has not always worked properly, for at some depths, at any rate, the salinities of the water samples, and also the temperatures, are impossible. If, for instance, at Stat. IV, the water at 400 m. actually had a salinity of 35·29 ‰ and a temperature of 2·46° C., it is impossible that the water at 850 m. could have had a salinity of 35·10 ‰ and a temperature of 2·05° C.; for the density of the former water would be about 1·02805, and that of the latter 1·02794. Either the salinity of the latter must have been about 35·24 ‰, or if the salinity be correct, which is more probable, its temperature must have been about 0·6° C. instead of 2·05° C.[2] The salinity, or more probably the temperature, for 850 m. at Stat. VI, is also wrong. The salinity may have been about 35·05 ‰ and the temperature about 0·5° C. The temperatures and salinities for 500 m. and 80 m. at Stat. III are also impossible, and so are those for 170 m. at Stat. II.[3]

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[1] It seems, however, probable that the shallowness of the current at Stats. 67, 65, and 63 is to some extent caused by the low sub-oceanic "Transverse Ridge" extending from Jan Mayen towards the shallow platform between Norway and Bear Island (see Mohn, 'The North Ocean', etc. l. c. Pl. I). It is striking how the isotherms and isohalines in Section XIII, Pl. XXXII, seem to follow the undulations of the bottom.

[2] Unfortunately Pettersson and Ekman, (Bih. K. Sv. Vet.-Akad. Handl. vol. 23, No. 4), do not mention how the temperatures and water-samples were taken. Supposing, however, they were taken with the Pettersson insulated water-bottle, it is probable that the insulation has been insufficient for temperatures from 850 m. (cf. above, pp. 10 *et seq.*). As the releasing arrangement of this water-bottle was somewhat imperfect, it is also possible that the bottle may sometimes have been closed in wrong depths. In the section on Pl. XXX I have corrected the evident errors of the temperatures.

[3] Even if the water-samples were originally correct, inaccuracies may have occurred from

But even making allowances for the lower values of the Swedish determinations and for the above evident inaccuracies, which may have been due to imperfections of the water-bottle, the fact remains that only in some few places did Arrhenius find water-strata with salinities approaching our value of 35·29 ‰. It does not seem very probable that the bottom-water filling the whole deep of the North Polar Basin, and forming a layer at least 3000 m. thick, can arise solely from such a meagre source. The only other way through which a portion of this bottom-water might come, is the continuation of the Gulf Stream belween Novaya Zemlya and the Franz Josef Archipelago. It has, however, been pointed out above, that this sea, as also the Kara Sea, is probably separated from the North Polar Basin by a shallow submarine ridge between the Franz Josef Archipelago and the Taimur Peninsula.[1] It seems therefore probable that the Gulf Stream west of Spitsbergen may have considerable variations, and the summer of 1896 has evidently been no very favourable season. In the summer of 1900 it must, however, have been still worse, for then the salinity of the Gulf Stream did not even reach 35·29 ‰, west of Bear Island. But in July, 1897, as mentioned on p. 227, the Gulf Stream west of Spitsbergen was evidently much more developed than in August, 1896, at any rate on the surface. In 1898 there may again have been an unfavourable season (see p. 227).[2] I consider it therefore probable that there is no constant influx of water of 35·29 ‰ into the North Polar Basin, but that it will more especially run in during seasons when the Spitsbergen Gulf Stream is greatly developed. Being much heavier than the rest of the water, when it has been sufficiently cooled down, it will run in at a greater rate, and will sink to the bottom and form the bottom-water of

evaporation through the cork stoppers of some glass bottles (cf. my paper in Nyt Mag. for Naturv. vol. 39, pp. 141 & 142) before the samples were examined in Stockholm; and this may perhaps also explain some of the irregularities in the salinities of Arrhenius's water-samples.

[1] Cf. pp. 277, 288, 289, 303.

[2] During the Norwegian North Atlantic Expedition in 1878, some few determinations were made of the specific gravity and salinity of the Gulf Stream water at various depths west of Spitsbergen, but the values obtained are evidently much too low. It seems probable that the water-bottle used did not close perfectly, and the water-samples have all been more or less mixed with surface-water. As examples may be mentioned that Mr. Hercules Tornøe, by hydrometer and titrations, found the salinities for the depths between 1000 and 3083 m. west of Spitsbergen for the most part varying between 34·2 ‰ and 34·9 ‰. (See H. Tornøe, 'Chemistry'. The Norwegian North Atlantic Exp. 1876–78, p. 64). We now know that the salinities of this bottom-water were probably very nearly 35·06 ‰ (or more correctly 35·08 or 35·09 ‰).

the North Polar Basin; and having a very slow circulation, it will not need very frequent fresh additions to keep up its high salinity.

The cold Bottom-Water of the Norwegian Sea. The origin of this water, which has a salinity of about 35·06 ‰ and a temperature below —1° C., has puzzled me much, as it seemed impossible that it could originate directly from the North Polar Basin. I considered it more probable that it might be formed by cooling on the surface somewhere in the northern regions of the Norwegian Sea itself. Capt. *Roald Amundsen's* observations of last summer (1901) seem, however, practically to solve the problem. From his temperatures and water-samples it appears that in the region north of Jan Mayen between Lat. 73° and 75° N. and Long. 1° and 10° W., the bottom-water of the Norwegian Sea approaches the surface (see Pl. XXXI). At Amundsens's Stat. 13, we find water of —1·4° C. and 34·97 ‰ at 50 m. and at 150 m. the temperature is —1·0° C. and the salinity 35·04 ‰; at greater depths the temperature is between —1° C. and —1·4° C., and the salinity is about 35·06 ‰, generally somewhat higher (the variations might, however, arise from inaccuracies of the determinations or the water-samples). I consider it very probable that the bottom-water of the Norwegian Sea is actually to a great extent formed in this region by admixture of the coldest water of the Polar Current with Atlantic water which has been much cooled down before it reaches this latitude. We have seen above that the minimum temperature of the Polar Current is situated at just about 50 or 60 m. But the chief constituent is evidently the Atlantic water, for otherwise the salinity of the bottom-water could not be so high as 35·06 ‰.

The polar water with which it is mixed comes from the north, running over the warm under-current branching off from the Gulf Stream west of Spitsbergen (and passing along the still unknown shallow ridge to the north; see above). As, however, there cannot be any considerable admixture of this cold, but less saline, water, the low temperature of —1·3° C. or —1·4° C. must to a great extent be obtained by cooling from the surface during the winter, when the bottom-water perhaps also comes still nearer to the surface. We have seen above that by the cooling during the winter, the surface-layers of the Gulf Stream become heavier, and this produces an eastward motion of the surface-strata overlying the bottom-water in the above region. At the same time the Polar

Current along the Greenland coast is somewhat increased during the winter, and thus the cold bottom-water at Amundsen's stations may be pressed still nearer to the surface, where it is rapidly cooled down. When it is sufficiently cooled to sink, it is replaced from the sides by water that is in its turn cooled down, and so the process is repeated. The salinity of the surface-water is also simultaneously increased by the formation of ice. We can thus understand that the water of the North Polar Basin probably does not play any significant, direct part in the formation of the bottom-water of the Norwegian Sea.

k. *Secular Changes in the Circulation of the North Polar Basin, and their Influence upon the Climate.*

It is evident that the oceanographical conditions of the North Polar Basin, have much influence upon the climate, and it is equally evident that changes in its conditions of circulation would greatly change the climatic conditions.[1] There are especially two circumstances that are of importance in this respect.

The considerable layer of lighter cold water covering the whole of the North Polar Basin has evidently an important effect. By protecting, on the one hand, the warm underlying water and preventing it from being directly cooled down by the radiation of heat, it makes the strata of the sea underneath 200 m. warmer than they would be if they were allowed to approach the surface; but on the other hand, by preventing the underlying warm water from giving off its heat to the atmosphere, it makes the climate of the Arctic Regions considerably colder. This layer of cold water with low density, which cannot sink when cooled, because it is much lighter than the underlying water, also greatly favours the formation of ice on the surface; and although this process sets free latent heat,[2] it increases the cooling of the surface of the sea by the emission of heat, as that surface is covered by a thicker, solid, non-conducting layer of snow and ice. But the relatively low temperature of the surface thus produced, will naturally also lower the temperature of the atmosphere.

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[1] Cf. Nansen, 'Fram over Polhavet', Christiania, 1897, vol. II, pp. 539, *et seq.* See also *idem*, 'In Nacht und Eis', revised edition, Leipzig, 1898, vol. II, pp. 508 *et seq.*

[2] This latent heat is also again engaged when the ice melts.

This layer of relatively light water has, however, also indirectly a cooling effect upon the Arctic climate, by reducing the convectional circulation of the Polar Sea. If there had been no such layer, the inflowing warm water would run near the sea-surface, and would be more cooled down; it would sink more rapidly, and this would again necessitate a more active influx of warm water along the surface, as well as a more active outflow of cooled water. In this manner more heat would actually be carried to the polar regions, and this heat would be given off to its atmosphere.[1]

How many degrees Centigrade the 200 m. thick, cold surface-layer, with low density, of the North Polar Basin, is able to lower the annual average temperature of the Arctic climate in these three ways, may be somewhat difficult to calculate; but the amount must at any rate be considerable.

Is it probable that it has been otherwise in earlier geological periods? We have seen that although the polar surface-layer with low salinity owes its existence to some extent to the precipitation of moisture over the Polar Sea itself, its chief sources are the volumes of river-water carried into the North Polar Basin from Siberia. If the Siberian and the American rivers in some earlier geological period had other courses, and were, for instance, to a great extent carried into the Pacific and the Atlantic, it is clear that the surface of the North Polar Basin would become somewhat warmer. But it is very doubtful whether such great changes in the courses of the rivers have actually occurred in any comparatively recent geological period.

Possible changes in the depths, or in the configuration of the coasts and the sea-bottom of the northern seas may, however, be of more importance as regards their circulation and their climate. It has been pointed out above that the transverse ridges between Scotland and Greenland over the Færoes and Iceland, and between Novaya Zemlya, Franz Josef Land, Spitsbergen and Greenland, have evidently a considerable retarding influence upon the convectional circulation of the Polar Seas, as they prevent to a great extent the cooled bottom-water from running back into the Atlantic. It is clear that if the depth of the sea over these ridges could be increased, it would greatly increase the convectional circulation; there would be a more

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[1] This increase of the circulation would, however, be checked by the reduction of the surface-layer conditioning the force of circulation, which is the chief cause of the present surface-current.

active influx of warm water into the Norwegian Sea and the North Polar Basin, and a correspondingly active outflow of cold water along the bottom. The surface of these seas and their climates would consequently become warmer, and it is clear that an increased influx of warm water would, for instance, greatly affect the climates of Scandinavia, Spitsbergen, etc. In a special memoir on the depths of the North Polar Basin, I am trying to prove that great oscillations of the sea-level of the Northern Atlantic, the Norwegian Sea, and the North Polar Basin, must repeatedly have occurred in comparatively recent geological periods. These oscillations may amount to at least 1000 m., and it is clear that they may have greatly influenced the circulation of the northern seas and their climatic conditions, even if the configuration of the sea-bottom and the transverse ridges were very nearly the same as they are at present. A subsidence of the land and the sea-bottom of some hundred metres, would greatly increase the influx of warm water, and would raise the temperature of the arctic regions, but more especially of Scandinavia, and to some extent also of Northern Russia and Siberia.

On the other hand, a lowering of the sea-level by 500 m., not to speak of 1000 m., would have a still greater effect in the opposite direction. Such changes in the sea-level have actually occurred. The Færoe-Iceland-Greenland Ridge, as also the ridge across Davis Strait, would then be elevated above sea-level along almost their entire length, except perhaps a narrow channel between the Færoes and Scotland, which would then be relatively deeper than it is at present.[1] The influx of warm water from the Atlantic would be cut off, the thickness, as also the extent, of the ice[2] covering the Polar Sea would be much increased, and the climate of these regions would become considerably colder; while the temperature of the Atlantic would be much warmer, as it would receive no ice or cold water from the Arctic Sea, and would not have to give off warm water for heating the Norwegian Sea and the North Polar Basin. It seems very probable, according to my view, that during periods with so low a sea-level—and such periods evidently have existed—the conditions have been such as would necessitate an ice-age in

[1] This channel has probably subsequently been filled up to some extent by loose material from glaciers, etc.

[2] The ice of the enclosed sea would have a tendency to increase in thickness gradually and slowly until it reached a certain limit, which would be determined by the subterranean heat of the Earth.

Scandinavia, whose countries would then acquire a climate probably colder than the present climate of southern Greenland, and possibly with no less precipitation.

From what precedes it will be understood that changes in the oceanographical conditions of the Norwegian Sea and the North Polar Basin—either by a reduction of the admixture of fresh water carried by the rivers, or still more by changes in the bathymetrical features of the Ocean, especially those of the entrance to these enclosed seas—will necessarily have a considerable effect upon the surface-temperature of the northern seas, and thus upon the climate of the surrounding regions. The changes would result either in a warmer climate in the northern regions, and simultaneously a cooling of the Atlantic region south of the Færoe-Iceland Ridge—the Atlantic having to give off more warm water and to receive more cold water—or in a colder climate in the north and a warmer climate in the Atlantic region south of the Færoe-Iceland Ridge, which would then almost completely separate the two seas, and prevent any appreciable circulation between them. There cannot therefore, according to my view, be much doubt that changes in the climate of the Northern regions have actually been thus effected even in comparatively recent geological periods. I consider it, for instance, very possible that the warmer post-glacial period, the so-called *Tapes Period*, when southern Molluscs, such as *Tapes decussatus*, etc., occurred on the coast of Norway,[1] and *Mytilus edulis* lived near the shores of Spitsbergen and the Franz Josef Archipelago,[2] may be explained by the existence of a somewhat higher sea-level, which would on the one hand increase the volume of warm water carried by the Gulf Stream over the Shetland-Færoe Ridge towards our coasts, and, what is perhaps equally important, would on the other hand increase still more the volume of cold polar water carried south through Denmark Strait, and thus probably reduce the East Icelandic Polar Current.[3] I

[1] Cf. W. C. Brøgger, 'Om de senglaciale og postglaciale nivåforandringer i Kristianiafeltet', Norges geologiske undersøgelse, No. 31, English Summary, pp. 704 *et seq.* Recent researches seem to prove that there has actually been a general submergence, at least along the coast of southern Scandinavia, during the warmer post-glacial period. (Cf. Holmboe, Nyt Mag. f. Naturv., vol. 39, p. 337). On Spitsbergen and Franz Josef Land there was a similar submergence.

[2] A shell of this mollusc was found by me on an old shore-line of Franz Josef Land, above the present sea-level.

[3] As the Scotland-Færoe-Iceland-Greenland ridge would on the whole be more submerged, the Gulf Stream and the Polar Current would be less blocked up at this ridge; the

consider it also very probable that at any rate a local Scandinavian glacial period might be produced by a lowering of the sea-level. It seems certain that oscillations of the sea-level must produce a succession of colder and warmer climates on our coasts.

But such oscillations, or other changes in the circulation of the northern seas, are hardly sufficient to explain the great changes that have occurred in the climatic conditions of the Northern Hemisphere; we cannot, for instance, merely in this manner obtain the necessary conditions for the warm Cretaceous and Tertiary climates of Spitsbergen, the New Siberian Islands, or the west coast of Greenland. But it is of course possible that such changes may have coöperated with other causes to produce specially favourable climatic conditions.

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former would acquire a more regular course into the Norwegian Sea along the Norwegian west coast and also into the North Sea, and the latter a more regular course along the Greenland coast, less hindered by the Irminger current, etc.

VI.

THE BIOLOGICAL CONDITIONS OF THE NORTH POLAR BASIN.

The biological conditions in the North Polar Basin are of a very peculiar nature. This sea is covered throughout the year by an ice-sheet, with a mean thickness of perhaps 3 m., which absorbs so much light, that even during the light summer the conditions for the development of plant-life in the water-strata underlying it are very unfavourable; and these conditions are made still more unfavourable by the very low temperature (below —1·5° C.), which approaches the freezing-point of the sea-water. In the narrow cracks and channels formed between the floes, the conditions are naturally better during the summer when they do not freeze and when there is daylight; but on the one hand these channels do not as a rule last long, being soon closed again by the movements of the ice, when the plant-life which may have been developed is again exposed to less favourable conditions,—and on the other hand the channels, during a great part of the summer, are covered with a layer of nearly fresh water produced by the surface-melting of the ice, this layer also evidently having a retarding influence upon the development of marine plant-life.[1] The result is that we found extremely

[1] There is perhaps one more circumstance that interferes with the development of plant-life at the sea-surface. In the autumn of 1893, I found no small quantity of diatoms and other forms near the surface of the more or less open sea to the north-west of the New Siberian Islands. But in October, when the ice formed, these forms near the surface were encased in the ice, to which they gave a brownish colour, and were thus prevented from developing any further; their shells were carried along with the ice, and prevented from falling to the bottom. When the ice gradually melted at the surface during the next summer, they would accumulate along with the dust from the air, and would help to give the surface of the ice its dirty brownish colour.

little plant-life in the interior of the North Polar Sea, and it is as a rule in vain that Mr. H. H. Gran has searched our plankton-samples for diatoms.[1]

But this scarcity of plant-life is naturally in its turn the cause of the extreme scarcity of animal life in this sea. Our samples of plankton-life contain, it is true, a comparatively great variety of species, especially of Crustacea;[2] but they contain as a rule no relatively great number of individuals; and these were collected by letting the tow-net hang in the water at the desired depth for days, or sometimes even weeks, while it was carried along by the drift of the ice, the net, notwithstanding, bringing up no greater an amount of plankton organisms than might, for instance, be taken during the summer in a single vertical haul through some metres of water, in the Norwegian Sea. This gives an idea of the extreme poverty of the plankton life in this sea.

These exceptional conditions must necessarily also have some influence upon the composition of the sea-water. It seems probable that the partial absence of organic life would increase the relative quantity of those constituents of the sea-water that are of essential importance in the production and sustenance of organisms; and the ice-covered polar seas may thus be assumed to act as a kind of lungs in the circulation of the Ocean. During the Fram Expedition, however, there was no opportunity of making chemical analyses of the sea-water, and we cannot give any information in this respect. It seems to be a fact that the polar waters possess peculiar conditions for an active development of plankton-life. Wherever the water of the polar currents divests itself of its ice-covering, and meets the warmer water from the south, there is a sudden and enormous development of life of all kinds during the summer, so much so that the sea-water, especially during the spring and early summer, is generally coloured a greenish brown by the great quantities of organisms developed in it, in those regions where polar water and Atlantic water meet and are mixed. These regions also contain the greatest fisheries of the world, *e. g.* Iceland, Newfoundland, the Lofoten Islands, etc.; and here, too, swarms of seals and whales occur (Denmark Strait, Newfoundland, Jan Mayen, the White Sea, etc.). In the sea east of Iceland, where the waters

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[1] Cf. H. H. Gran, 'Diatomaceæ from the Ice-Floes and Plankton of the Arctic Ocean', vol. IV, Memoir XI, of this Report.

[2] Cf. G. O. Sars, 'Crustacea', vol. I, Memoir V, of this Report.

of the East Iceland Polar Current spread over the Atlantic water, Dr. Hjort discovered, in 1900, quantities of pelagic cod fish (Gadus morrhua, G. carbonarius, etc.) and herring, feeding on the abundant plankton-life. This sea is also the best region for the bottlenose whale (*Hyperoödon diodon*) fisheries.

The explanation, according to my view, is very clear. Through the waters from the land, especially through the Siberian and American rivers (and also the North European rivers), the North Polar Basin is continually receiving additions of those constituents (especially compounds containing nitrogen,[1] but perhaps also phosphoric acid and silica, etc.) which are always only present in the sea-water in minute quantities, but which form the necessary base for the development of plant-life. In other parts of the Ocean, these substances will help to sustain the organic life as soon as they reach the sea, but this will not be the case to such an extent in the ice-covered polar sea, where they will consequently accumulate more or less without being used, as long as the water is covered by the ice. The low temperature will also act in the same direction, on the one hand retarding the development of organic life, and on the other hand perhaps favouring the absorption of ammonia.

The changes in the amount of free oxygen and nitrogen (as gas), and free carbonic acid, contained in the sea-water, is probably of little importance in this respect, as in most places there is present sufficient free oxygen, as well as carbonic acid, to give the necessary conditions for the sustenance of organic life; but some effect may nevertheless be produced by the fact that the polar surface-water, on account of its low temperature, has a great capacity for absorbing oxygen (and carbonic acid?) from the atmosphere; and as there is little organic life to use it, the water of the polar surface-current becomes gradually saturated with oxygen, and when somewhat heated in more southern latitudes, becomes supersaturated. It seems not improbable that this latter circumstance may also have some stimulating effect upon organic life.

When the polar waters, with these gradually accumulated favourable conditions for organic life, are carried southward by the polar current towards

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[1] Cf. K. Brandt, 'Ueber den Stoffwechsel im Meere, Kiel,' 1899.

lower latitudes, the ice-covering is gradually removed by melting; the light obtains access to the water-surface, and the formation of chlorophyl becomes possible; and simultaneously the temperature of the water is somewhat increased, which greatly facilitates the assimilation of nourishing substances. Germs and organisms are also present in sufficient quantity to form a nucleus. The result of this sudden change of conditions must necessarily be a sudden and active flourishing of the vegetable, as well as the animal, plankton-life in all regions where the waters of polar currents carrying ice meet the warmer waters from the Atlantic.[1]

From what has been pointed out above, it seems probable that the water of the ice-covered North Polar Current may contain more compounds containing nitrogen (nitrates, nitrites, ammonia) or similar substances, than the Atlantic water, but during the Fram Expedition there was no opportunity of making analyses of this kind. It is, however, not improbable that future research may bring to light interesting facts in this respect.

Postscript.

At the moment when this last sheet is going to press, I have received two highly interesting papers on the influence of bacteria on the nitrates and nitrites in sea-water, viz. *K. Brandt,* 'Ueber den Stoffwechsel im Meere, 2. Abhandlung', Wissenschaftliche Meeresuntersuchungen, herausgegeben von der Kommission zur Untersuchung der deutschen Meere in Kiel und der Biologischen Anstalt auf Helgoland; Abtheilung Kiel, Neue Folge, vol. 6; and *H. H. Gran,* 'Studien über Meeresbakterien 1. Reduction von Nitraten und Nitriten', Bergens Museum's Aarbog 1901, No. 10.

Prof. *Brandt* assumes that the greater productivity of the colder areas of the Ocean, as regards organic life, may be due to the fact that the activity of the bacteria ("denitrificirende Bakterien") decomposing the minute quantities

[1] *Middendorf* has already suggested that the abundance of life, fish, etc., on the Finmark and Murman coasts may in some way be due to the meeting 'der Ausläufer des Golfstroms mit den nordischen Gewässern'. Petermann's Mitteilungen, 1871, p. 32.

in the sea-water of nutritive salts containing nitrogen, is greatly checked by the lowering of the temperature. Hence these minute quantities will not be decomposed to such an extent in the colder areas as in warmer seas, and the conditions for higher organic life may be greatly improved by a lower temperature of the water.

Mr. *H. H. Gran* proves that the activity of these denitrifying bacteria is also greatly conditioned by the presence of constituents containing carbon (Kohlenstoffverbindungen), which must be present in the sea-water in quantities at least four times as great as those of nitrates or nitrites (l. c., p. 21). He thinks that these conditions may generally be present in the shallow coast waters, but regards it as more doubtful whether they exist in the open sea.

It will be easily seen that both these assumptions will lead to the conclusion that the surface-water of the North Polar Basin (the true Polar water) must possess specially favourable conditions for higher organic life. On the one hand the very low temperature (generally about —1·5° C.) practically prevents the decomposition by the bacteria of the nitrates and nitrites received from the rivers. On the other hand the amount of constituents containing carbon, necessary for the activity of these bacteria, is probably very small in the waters of the North Polar Basin, even on its coasts, because there is relatively very little organic life to produce them (*e. g.* the mud from the Siberian coast contains very little organic matter), and the low temperature greatly retards the decomposition of the organic substances. The result must be that as the thick ice-covering prevents the development of plant-life, the nutritive constituents containing nitrogen must be stored up in the surface-water of the North Polar Basin, until this true Polar water divests itself of its ice-covering in lower latitudes, and light obtains access to the water.

Prof. Brandt mentions that according to *C. Schmidt* the colder waters (from the Norwegian Sea and Arctic Sea) contain more phosphoric acid and silica than the warmer waters from southern seas.[1] If this observa-

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[1] C. Schmidt, 'Hydrologische Untersuchungen', Bull. Acad. Petersburg, vol. 24, 1878, pp. 177 *et seq.* Cf. also J. Murray and R. Irvine, 'On Silica and the Siliceous Remains of Organisms in Modern Seas', Proceed. R. Soc. Edinburgh, vol. 18, 1892, pp. 229—250.

tion be correct, it may be explained by the fact that the colder northern waters are more or less mixed with the waters of the Polar current coming from the North Polar Basin, where there is little organic life to assimilate the phosphoric and silicic acid dissolved in the sea-water.

THE NORWEGIAN NORTH POL

ctions I to XIV.

Approxima OF TEMPERAT on the in Ju

ations along the Fram's Route, 1893–1896.

" of the Norw. N. Atlantic Expedition, 1878.

" of the Michael Sars 1900.

" of Capt. R. Amundsen, 1901.

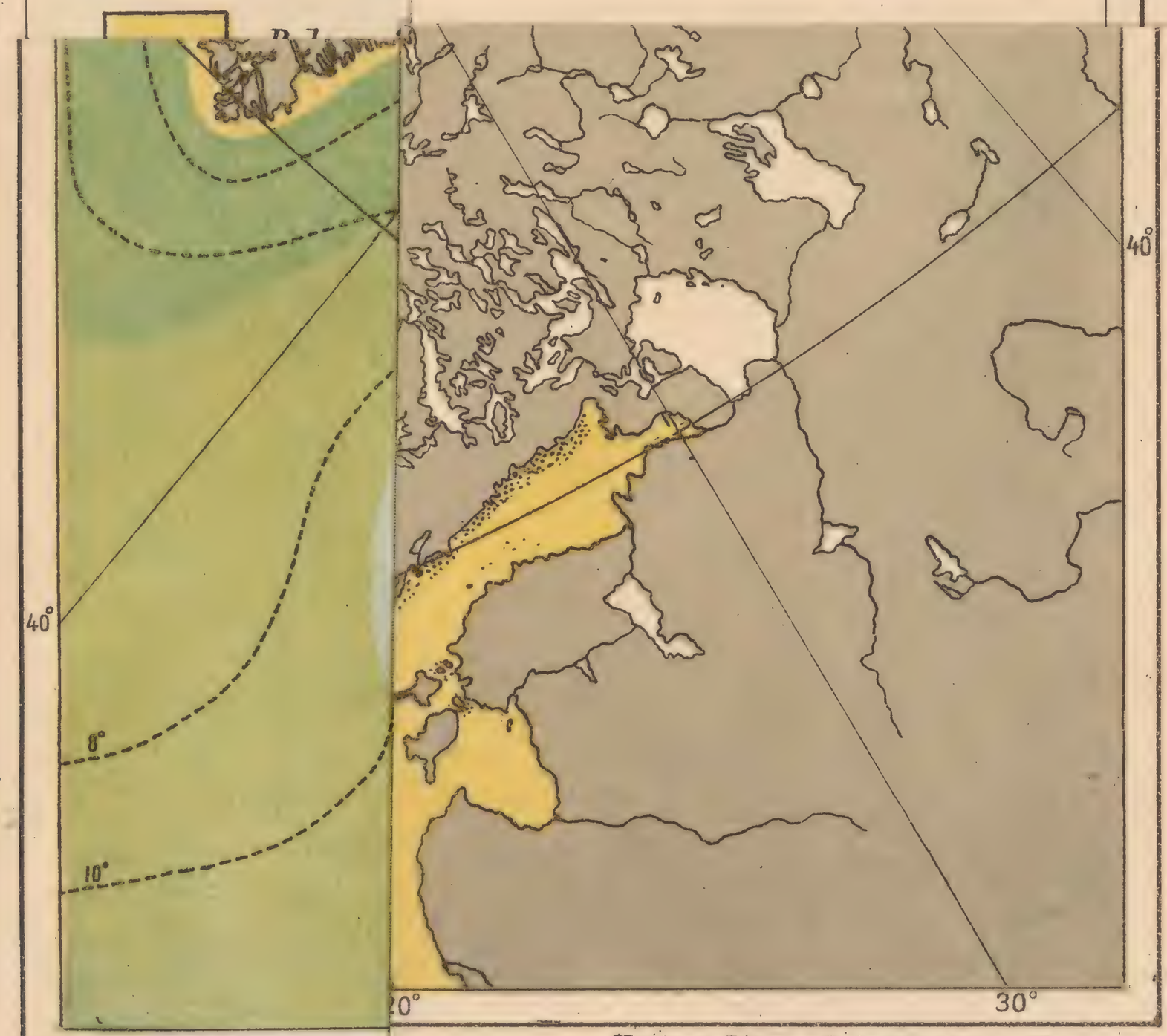
" of Capt. C. Ryder, 1891–1892.

" of the Kolthoff Expedition, 1900.

rection and Velocity of the Permanent Surface

rrent. 1·5 m.m. equal to 0·1 naut. mile in 24 hours.

4° ------ Isotherm.



Kart og Litografieringskontoret, Chr.a.

Approximate Mean Distribution of TEMPERATURE (°C) AND SALINITY ‰ on the Sea-Surface in July and August

4° ------ Isotherm.

Below 32‰	34·75‰ 35‰
32‰ 34‰	35·‰ 35·2‰
34‰ 34·75‰	Above 35·2‰

—o— Sections I to XIV.

1–26 Stations along the Fram's Route, 1893–1896.

262–338 " of the Norw. N. Atlantic Expedition, 1878.

M13–M67 " of the Michael Sars 1900.

A13–A23 " of Capt. R. Amundsen, 1901.

IX–XXVII " of Capt. C. Ryder, 1891–1892.

F1–F2 " of the Kolthoff Expedition, 1900.

⊢----→ Direction and Velocity of the Permanent Surface Current. 1·5 m.m. equal to 0·1 naut. mile in 24 hours.

Probably Shallow Plateau

Submarine Ridge

Iceland-Greenland Ridge

Transverse Ridge

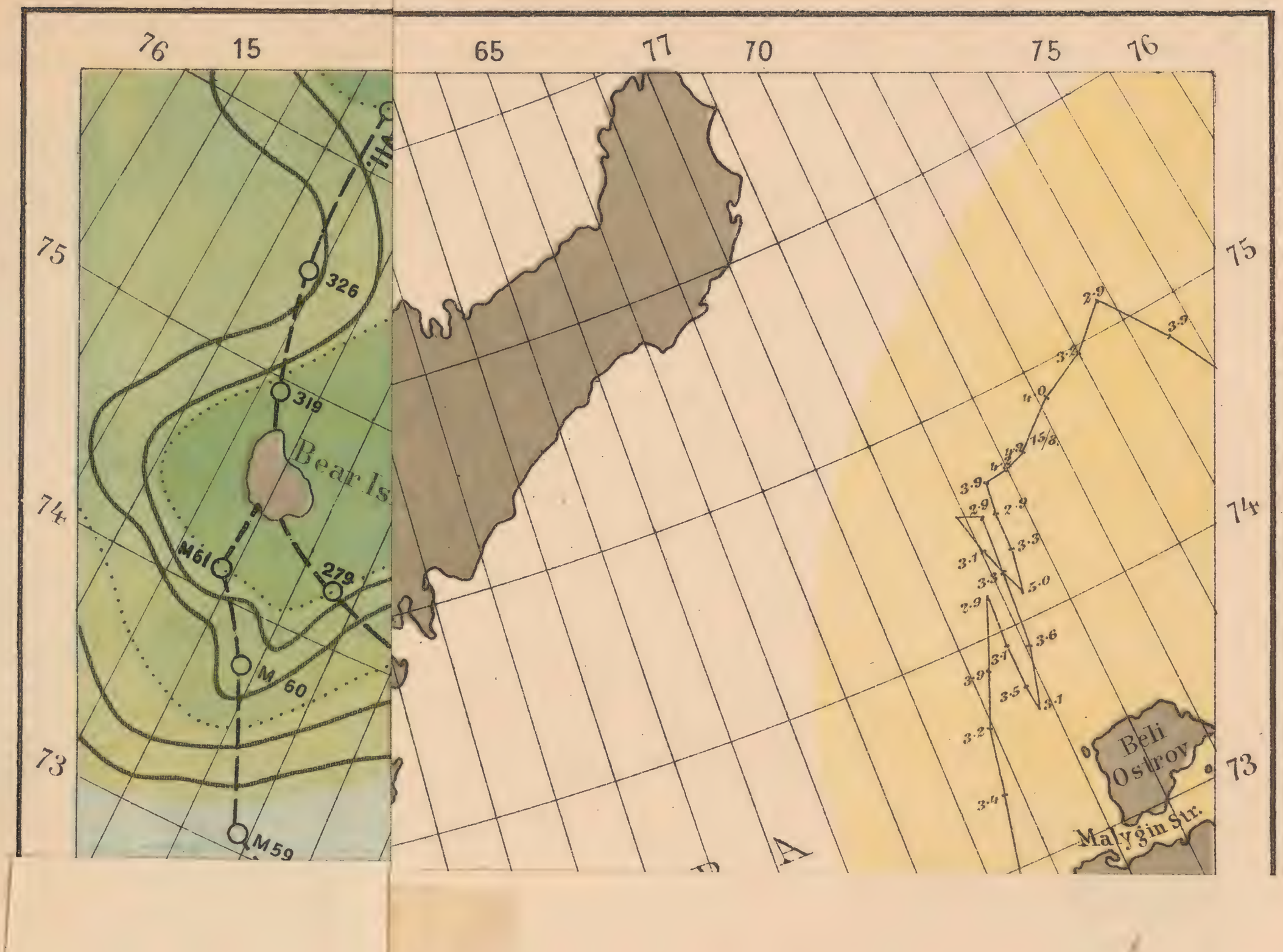
Low Transverse Ridge

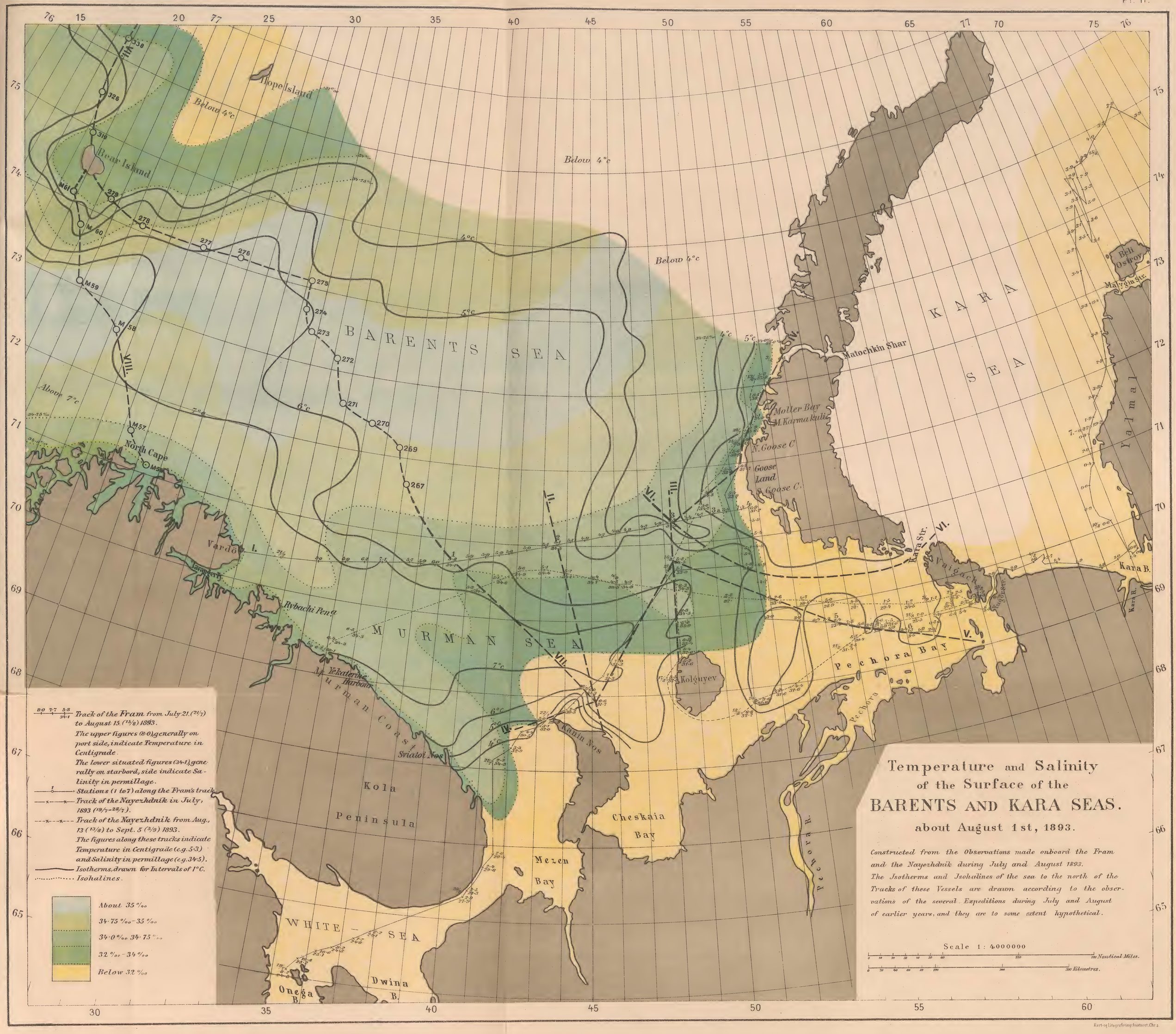
Faroe-Iceland Ridge

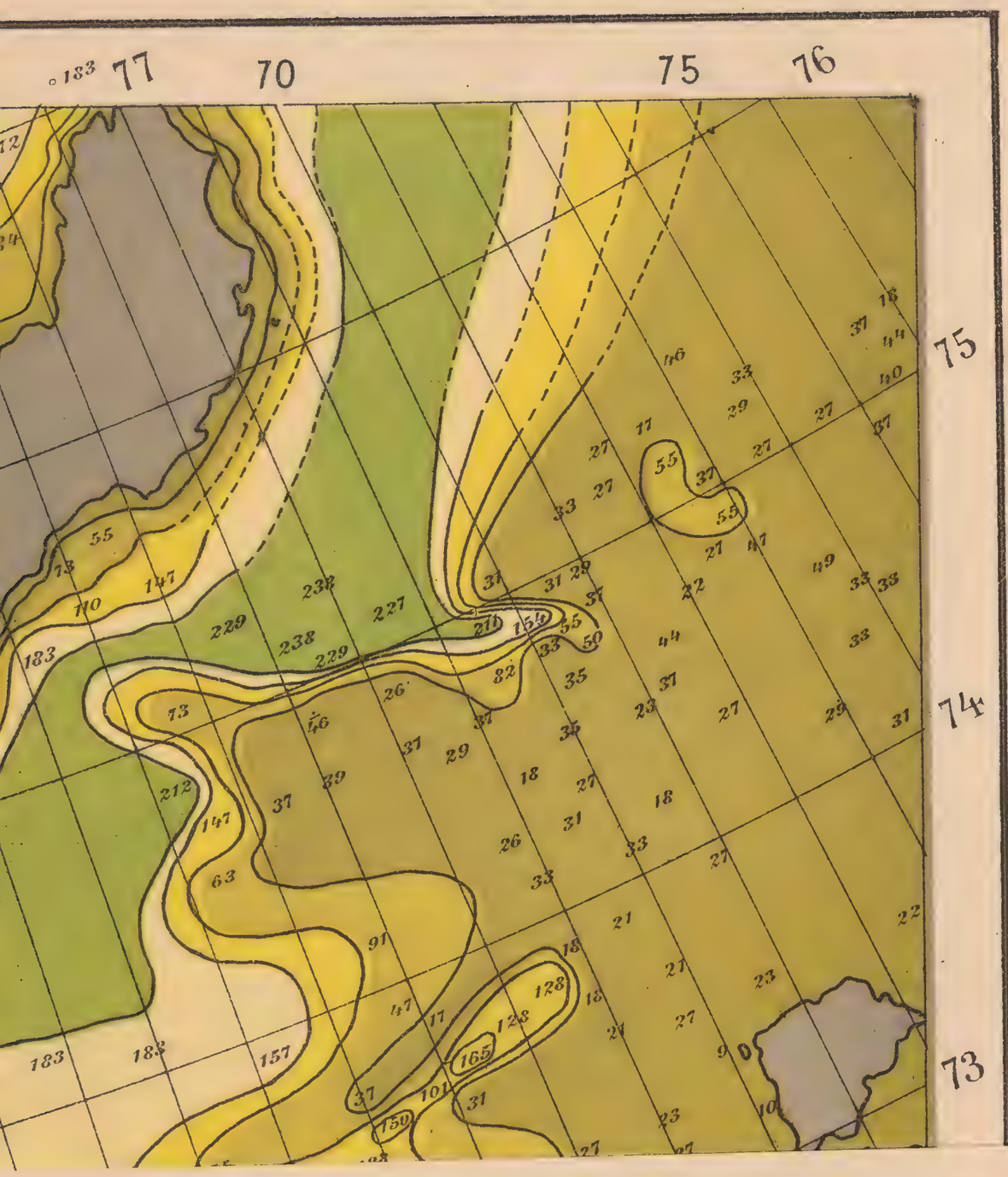
Faroe-Shetland Ridge

0° Greenwich Meridian.

Kart og Litograferingskontoret, Chr.a.


76
15
65
77
70
75
76
75
74
73
326
319
M61
279
M 60
M59
Bear Is
2·9
3·3
4·0
4·2
15/8
3·9
2·9
3·7
5·0
3·6
3·5
3·2
3·4
Beli
Ostrov
Malygin Str.


Temperature and Salinity
of the Surface of the
BARENTS AND KARA SEAS.
about August 1st, 1893.
Constructed from the Observations made onboard the Fram and the Nayezhdnik during July and August 1893.
The Isotherms and Isohalines of the sea to the north of the Tracks of these Vessels are drawn according to the observations of the several Expeditions during July and August of earlier years, and they are to some extent hypothetical.
Scale 1 : 4000000
Nautical Miles.
Kilometres.
Track of the Fram from July 21. (21/7) to August 15. (15/8) 1893.
The upper figures (8·0), generally on port side, indicate Temperature in Centigrade.
The lower situated figures (34·1), generally on starbord, side indicate Salinity in permillage.
Stations (1 to 7) along the Fram's track.
Track of the Nayezhdnik in July, 1893 (19/7-28/7).
Track of the Nayezhdnik from Aug., 13 (13/8) to Sept. 5 (5/9) 1893.
The figures along these tracks indicate Temperature in Centigrade (e.g. 5·3) and Salinity in permillage (e.g. 34·5).
Isotherms, drawn for Intervals of 1°C.
Isohalines.
About 35 ‰
34·75 ‰ - 35 ‰
34·0 ‰ 34·75 ‰
32 ‰ - 34 ‰
Below 32 ‰
BARENTS SEA
KARA SEA
MURMAN SEA
WHITE SEA
Hope Island
Bear Island
North Cape
Vardö
Rybachi Pen.
Murman Coast
Kola Peninsula
Sviatoi Nos
Kanin Nos
Kolguyev
Cheskaia Bay
Mezen Bay
Pechora Bay
Pechora
Pechora R.
Kara B.
Kara Str.
Yalmal
Matochkin Shar
Moller Bay
N. Goose C.
Goose Land
Onega B.
Dwina B.
Below 4°c
Above 7°c


77
70
75
76
75
74
73

Land
Sea Level
50 Metres
100 "
150 "
200 "
250 "
300 "
350 "
400 "
450 "
Below 450 m.

Bathymetrical Chart
of the
BARENTS AND KARA SEAS.
1901
By Fridtjof Nansen.

Compiled from latest Sources, including soundings of the Fram, 1893; the Nayezhdnik, 1893; Lieut. Zhdanko, 1894-95; Dr. Knipowitch, 1898-1901; Prof. Nathorst, 1898; the Heimdal, 1900; Capt. Roald Amundsen, 1901; Admiral Makaroff, 1901; the Norwegian Coast Survey, etc.

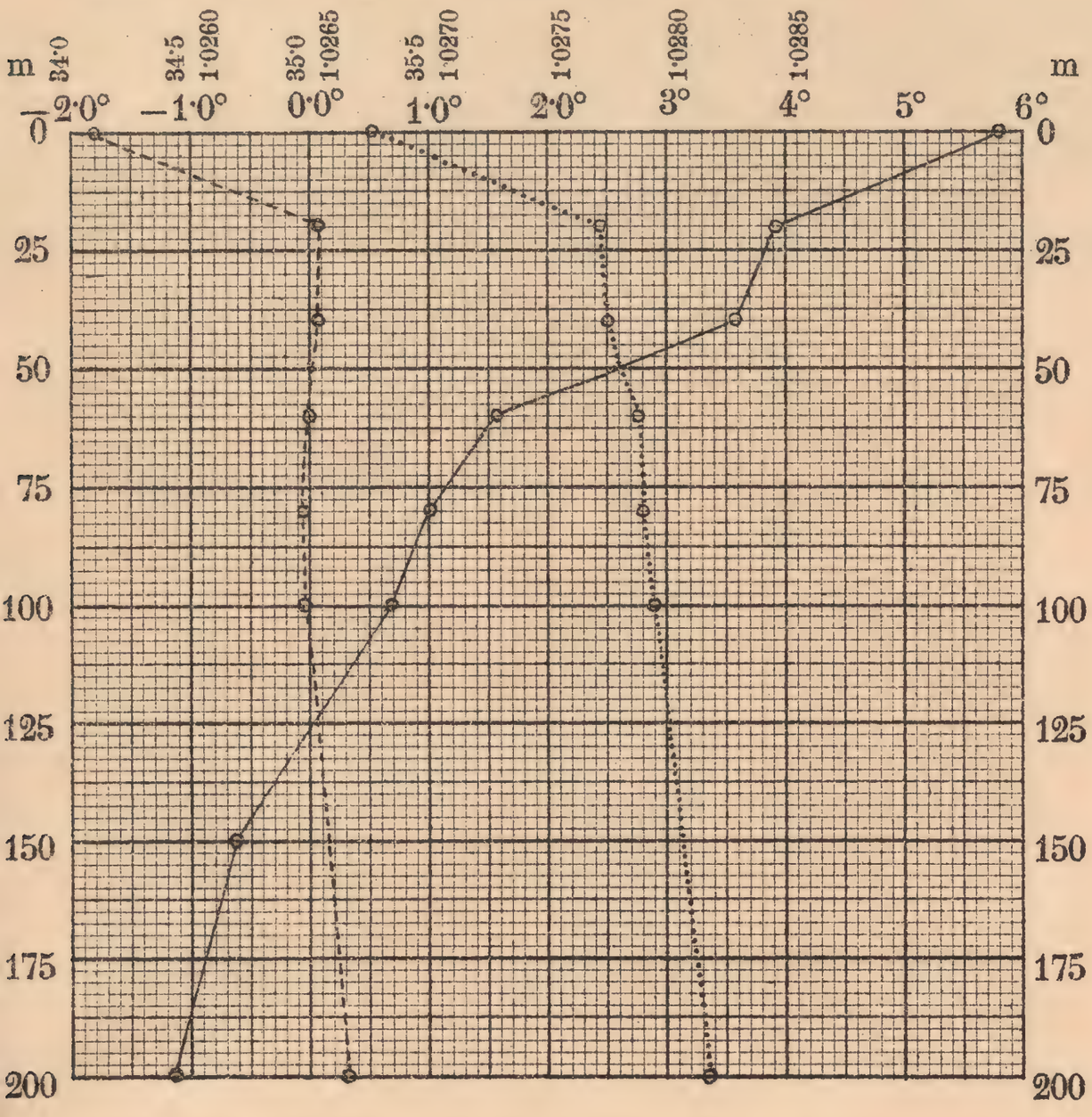
——— *Isobaths drawn for Intervals of 50 Metres.*
167 Soundings in Metres.

Scale 1 : 4000000

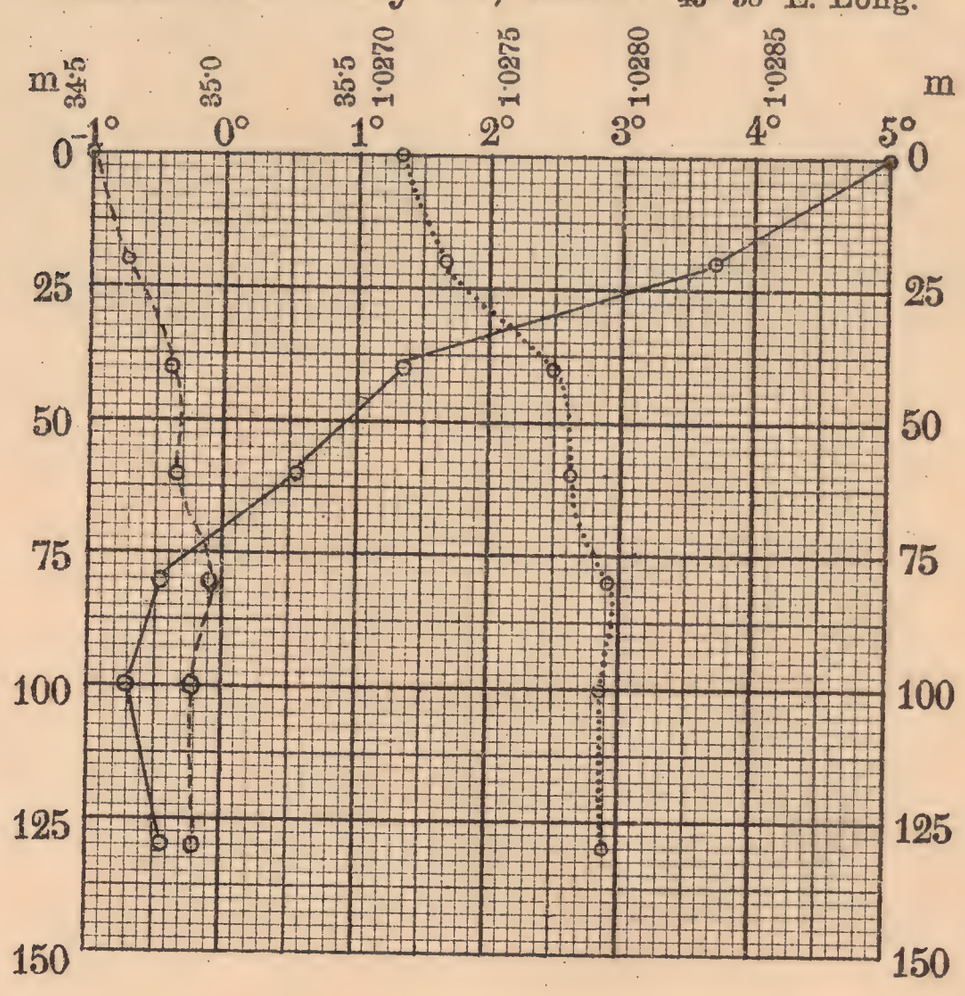
0 10 20 30 40 50 60 120 180 Nautical Miles.
0 20 40 60 80 100 200 300 Kilometres.

Kart-og Litograferingskontoret, Chr.ania.

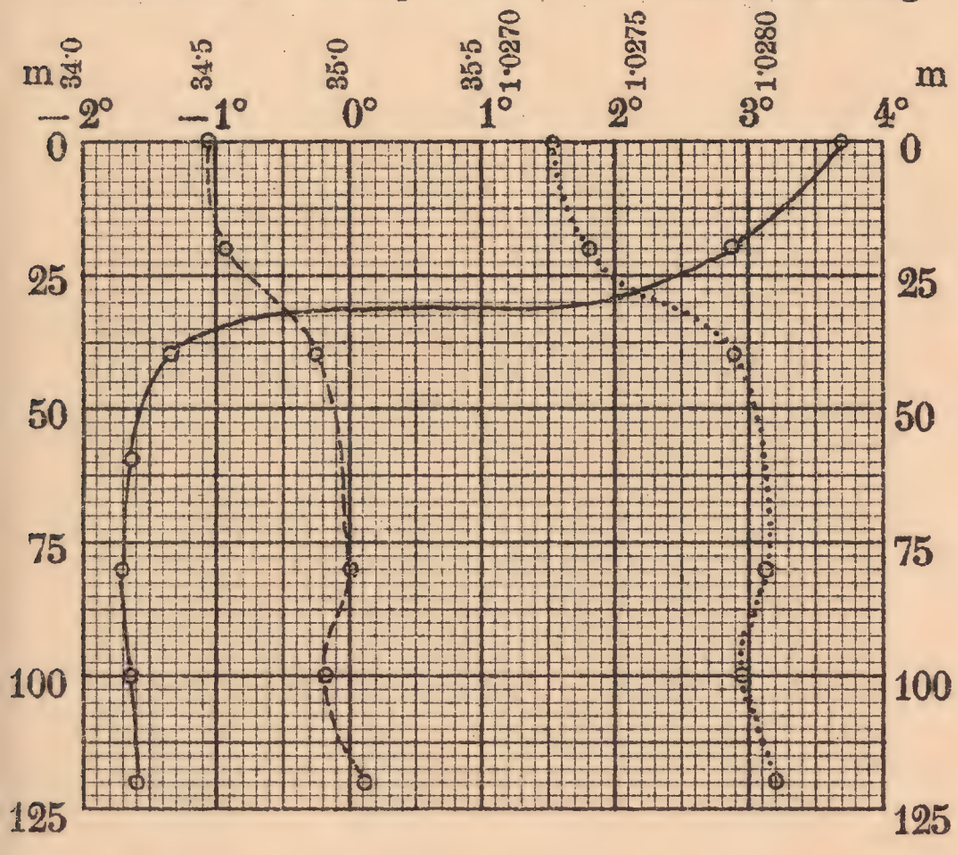
Station 1. July 22, 1893. 70° 43′ N. Lat. 39° 20′ E. Long.



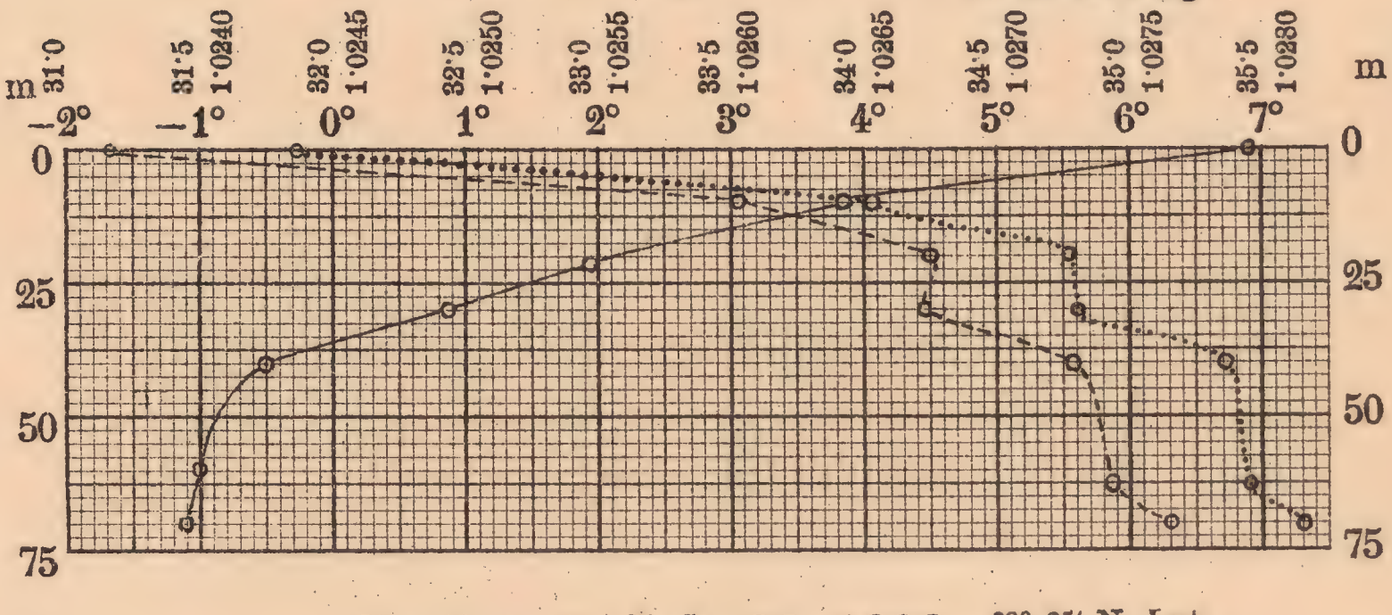
Station 2. July 23, 1893. 71° 1′ N. Lat. 43° 38′ E. Long.



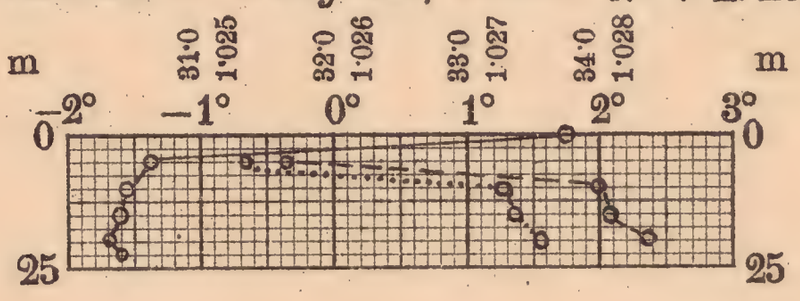
Station 3. July 24, 1893. 71° 17′ N. Lat. 48° 22′ E. Long.



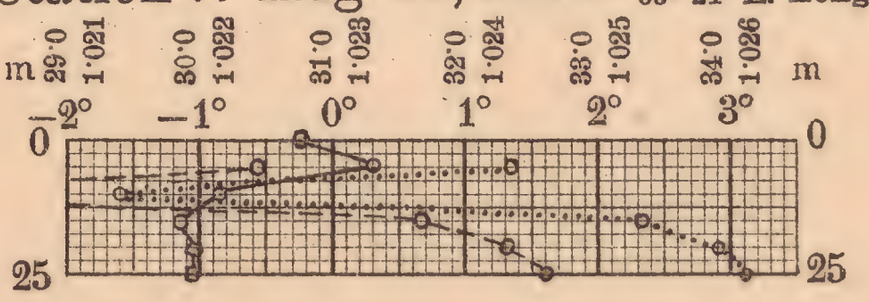
Station 4. July 25, 1893. 71° 23′ N. Lat. 51° 36′ E. Long.



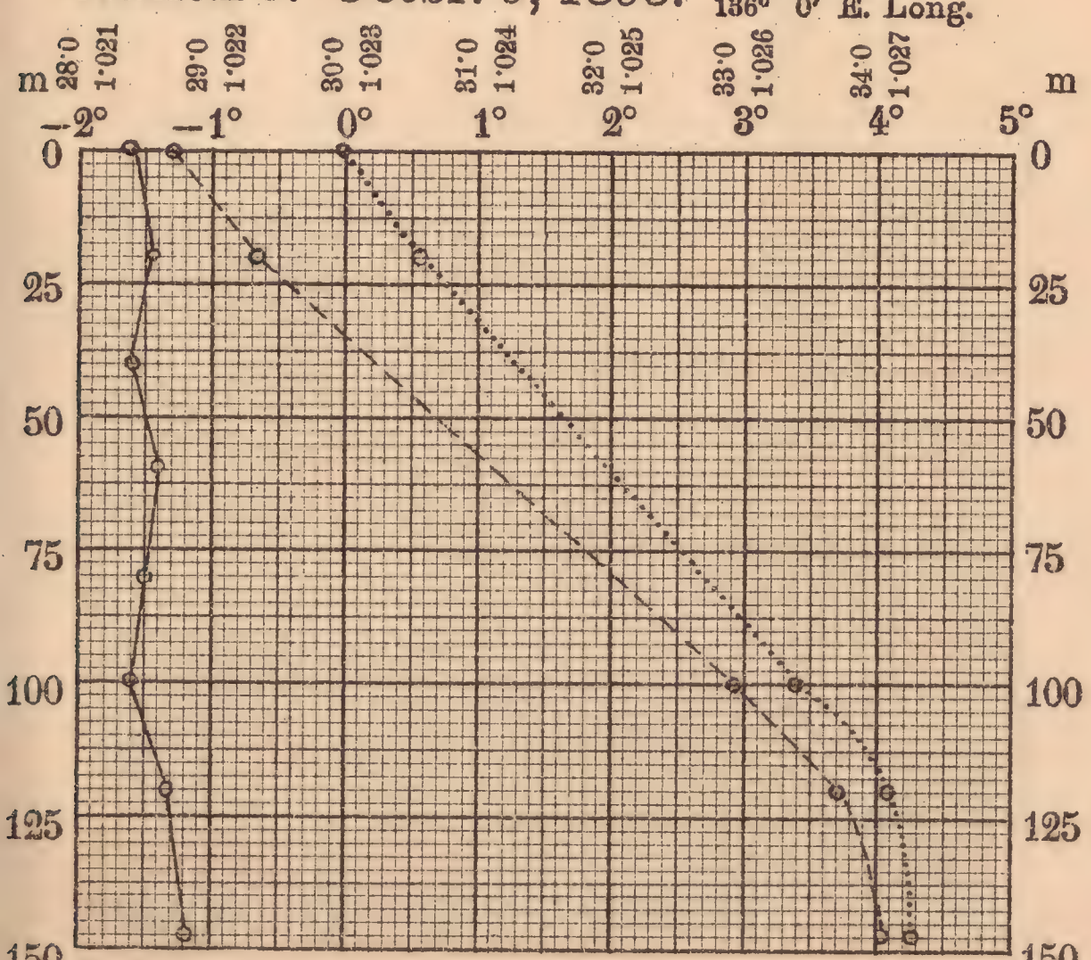
Station 6. July 28, 1893. 69° 25′ N. Lat. 57° 7′ E. Long.



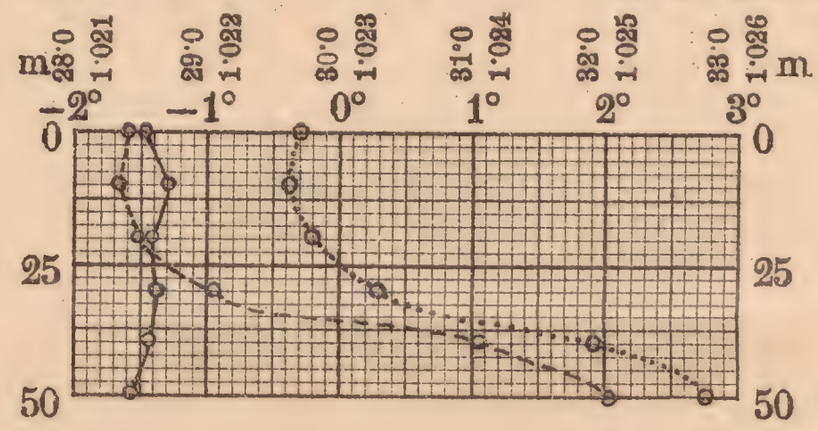
Station 7. Aug. 11, 1893. 71° 21′ N. Lat. 66° 24′ E. Long.



Station 9. Octbr. 9, 1893. 73° 20′ N. Lat. 136° 0′ E. Long.

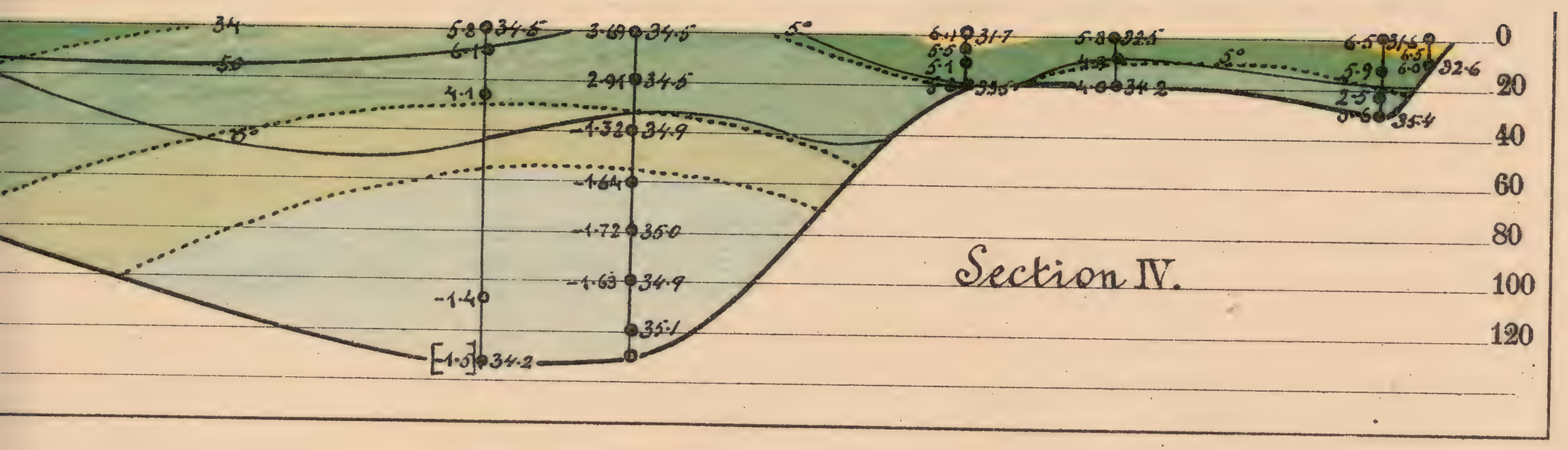


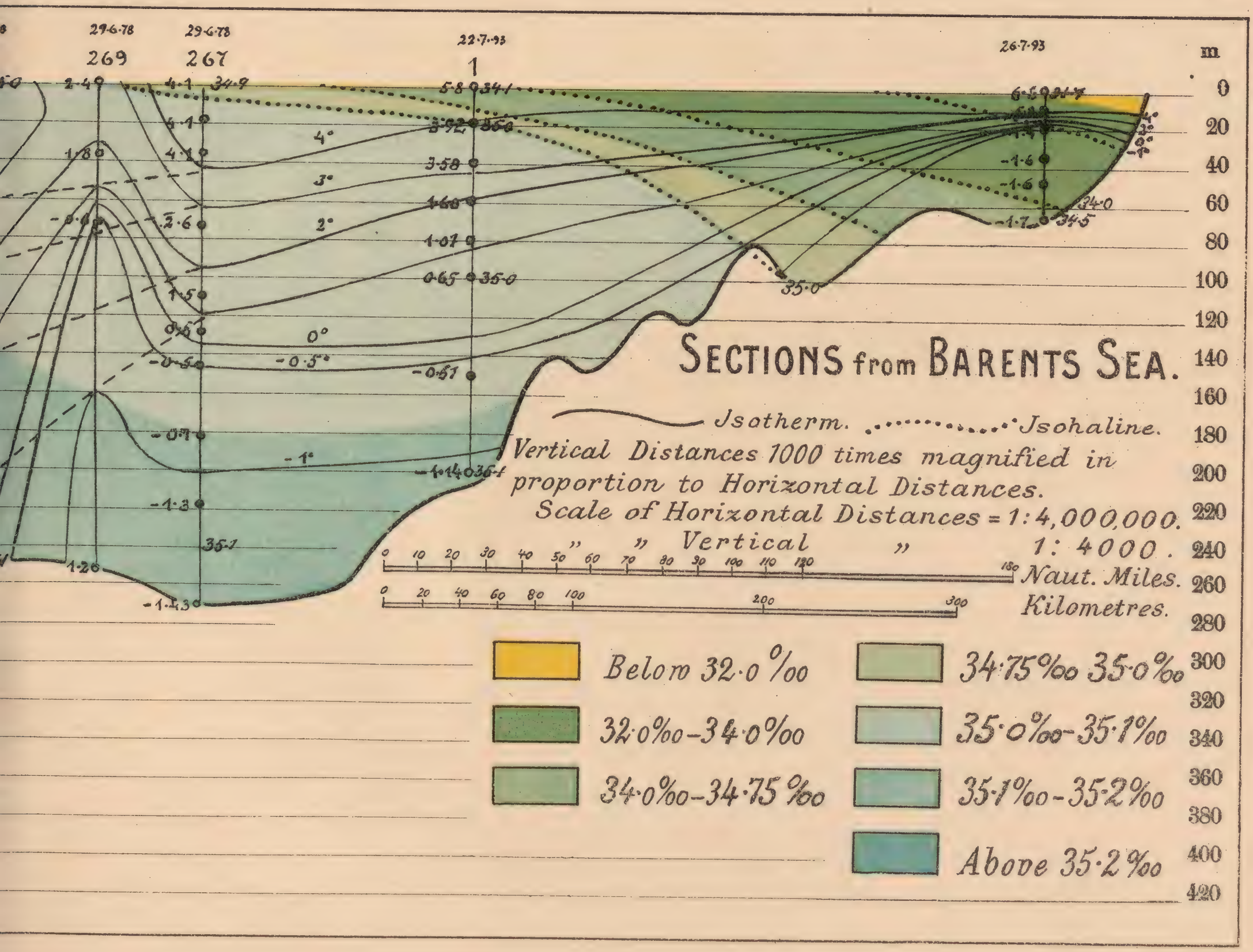
Station 11. Nov. 9, 1893. 77° 55′ N. Lat. 137° 50′ E. Long.

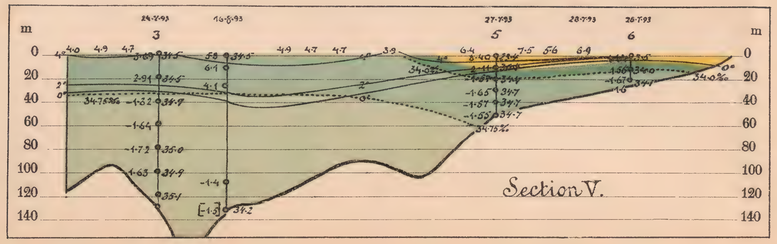


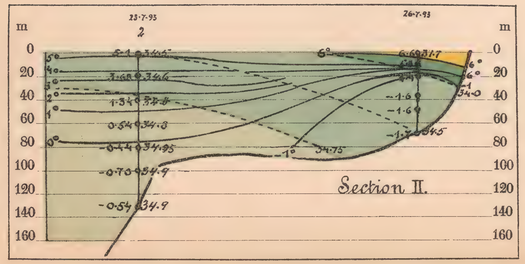
Station 5. July 27, 1893. 69° 43′ N. Lat. 54° 23′ E Long.

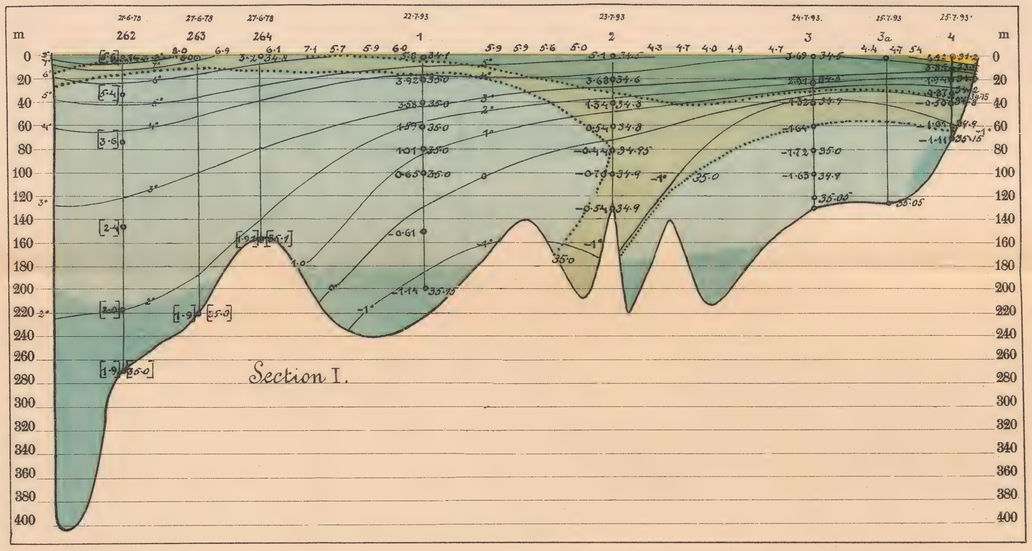
CURVES OF TEMPERATURE, SALINITY, AND DENSITY $(S\frac{t}{4^\circ C.})$ 1893.

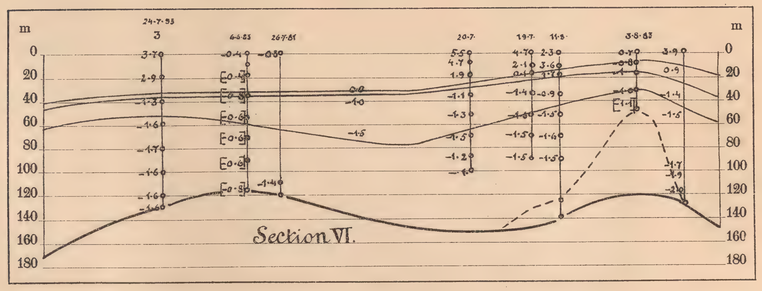

Section IV.

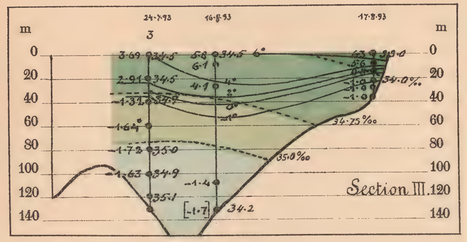

SECTIONS from BARENTS SEA.
Isotherm. Isohaline.
Vertical Distances 1000 times magnified in proportion to Horizontal Distances.
Scale of Horizontal Distances = 1:4,000,000.
" " Vertical " 1: 4000.
Naut. Miles.
Kilometres.
Below 32·0 ‰
32·0‰-34·0‰
34·0‰-34·75‰
34·75‰ 35·0‰
35·0‰-35·1‰
35·1‰-35·2‰
Above 35·2‰

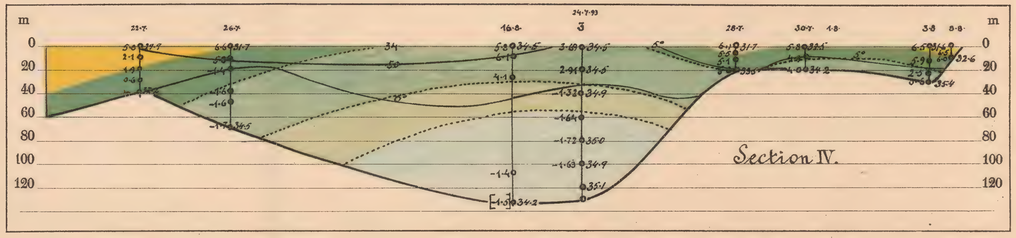

Section V.

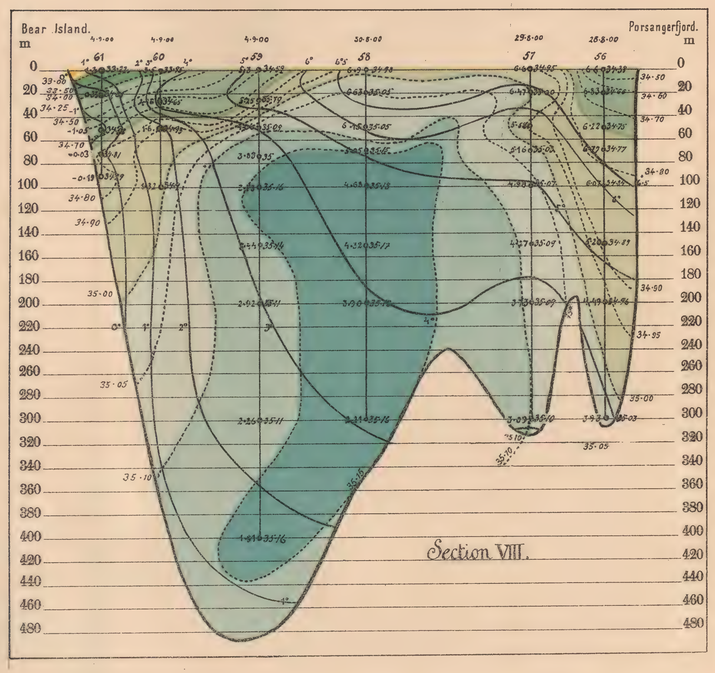

Section II.

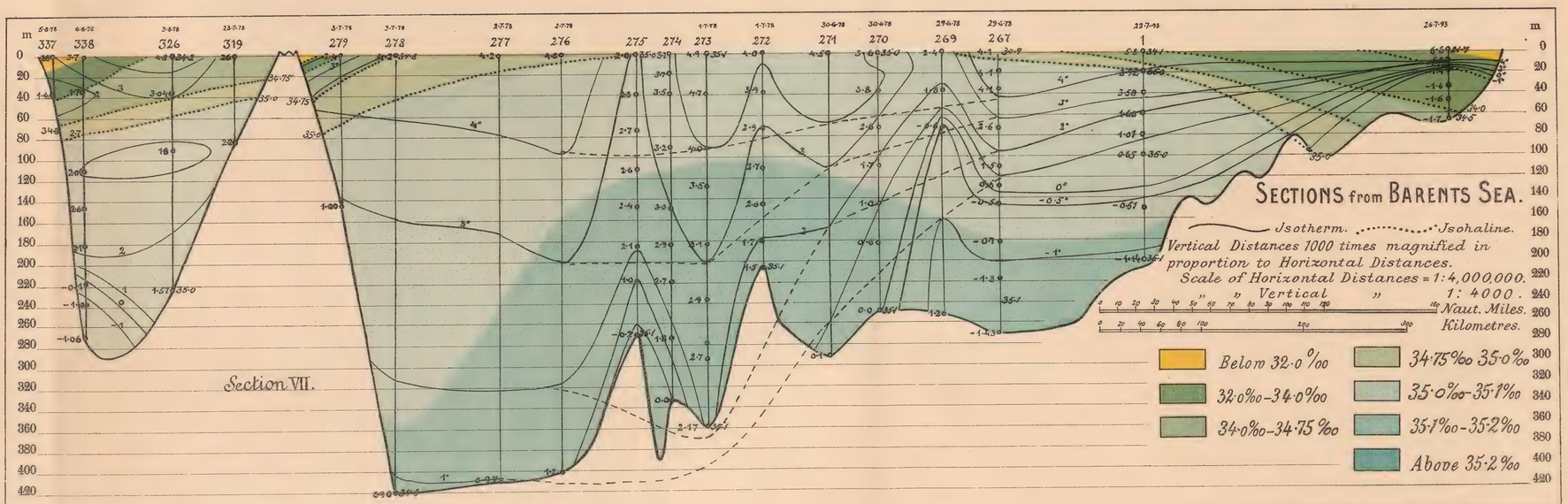

Section I.

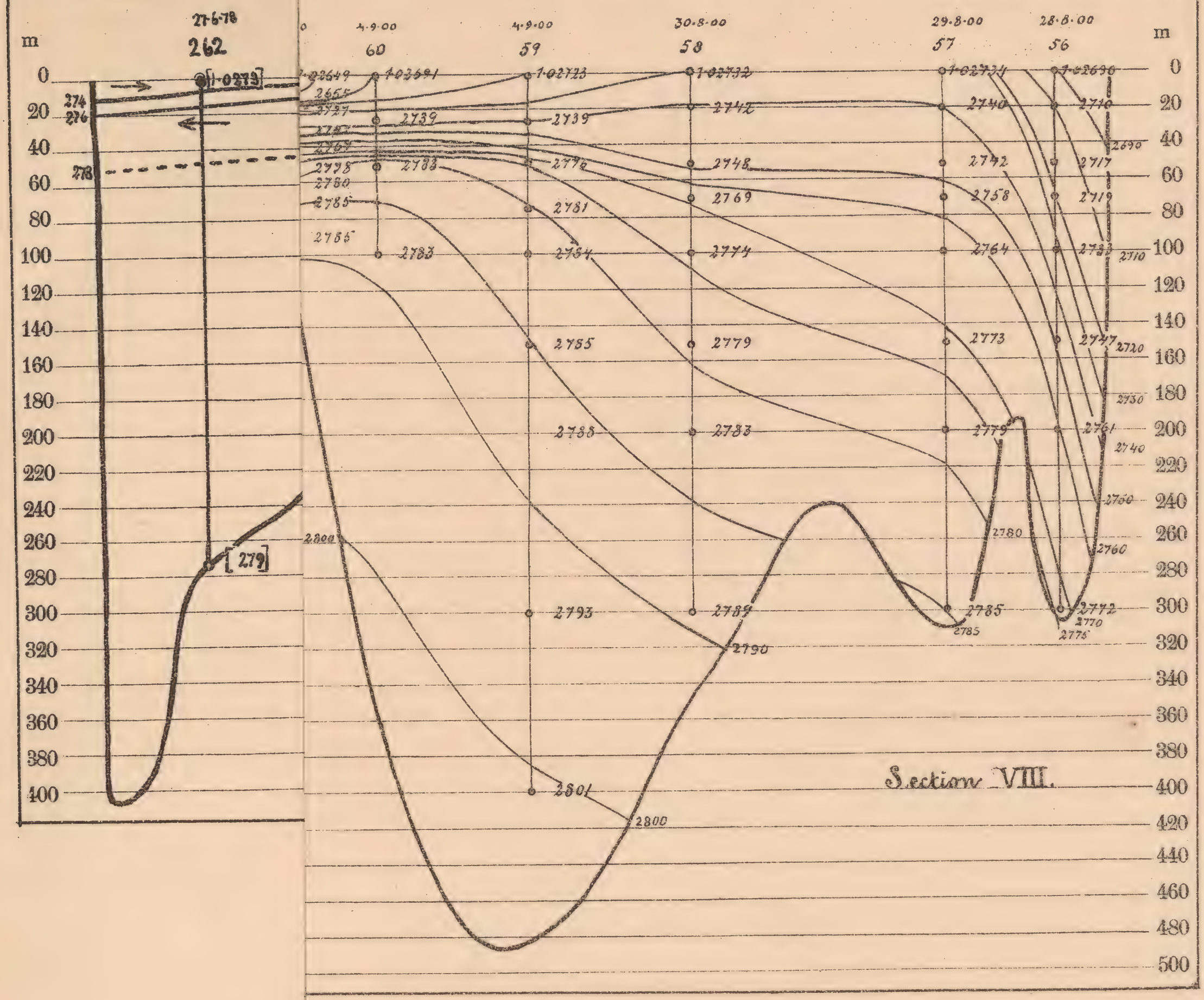

Section VI.


Section III.


Section IV.


Bear Island.
Porsangerfjord.
Section VIII.


Section VII.
SECTIONS from BARENTS SEA.
Isotherm. Isohaline.
Vertical Distances 1000 times magnified in proportion to Horizontal Distances.
Scale of Horizontal Distances = 1:4,000,000.
" " Vertical " 1:4000.
Naut. Miles.
Kilometres.
Below 32·0 ‰
32·0‰-34·0‰
34·0‰-34·75‰
34·75‰ 35·0‰
35·0‰-35·1‰
35·1‰-35·2‰
Above 35·2‰



SECTIONS from BARENTS SEA.

~ Isopyknal.

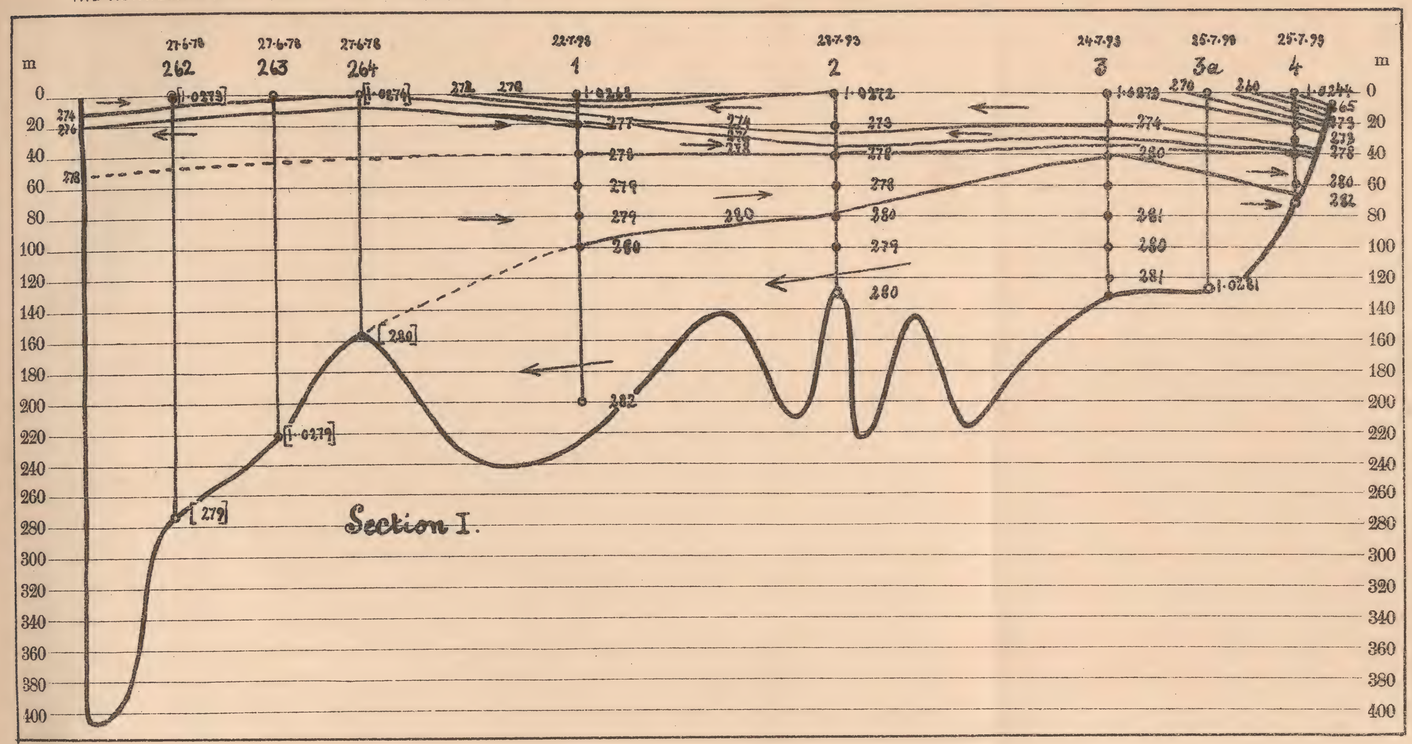
Vertical Distances 1000 times magnified in proportion to Horizontal Distances.

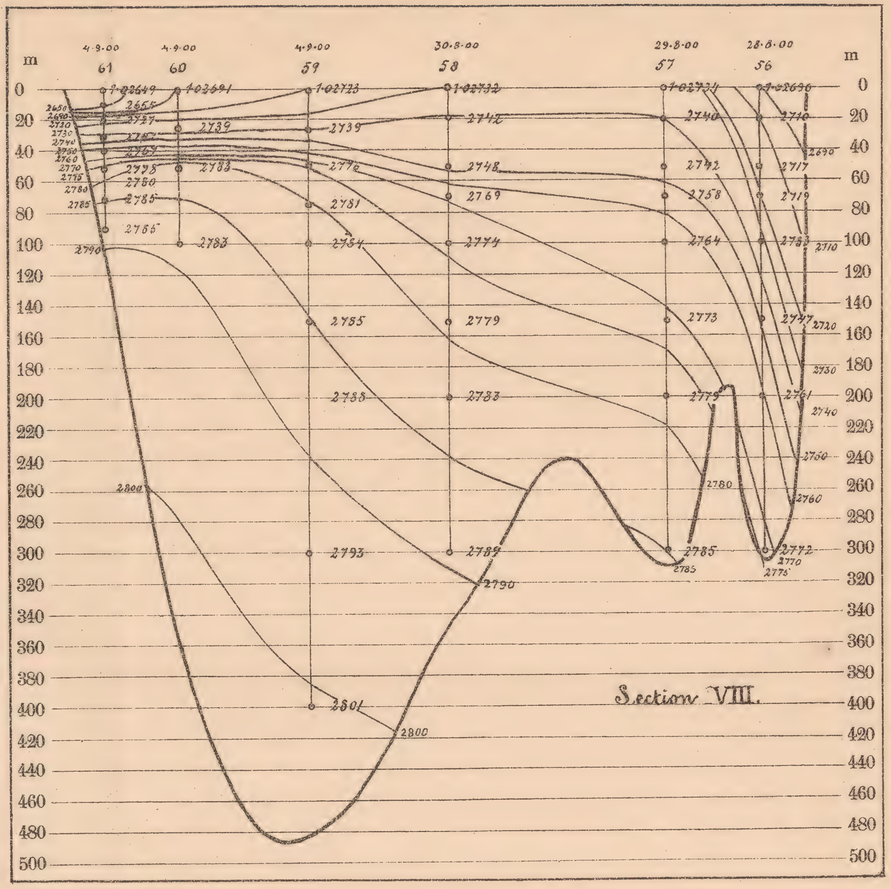
Scale of Horizontal Distances = 1:4,000,000.

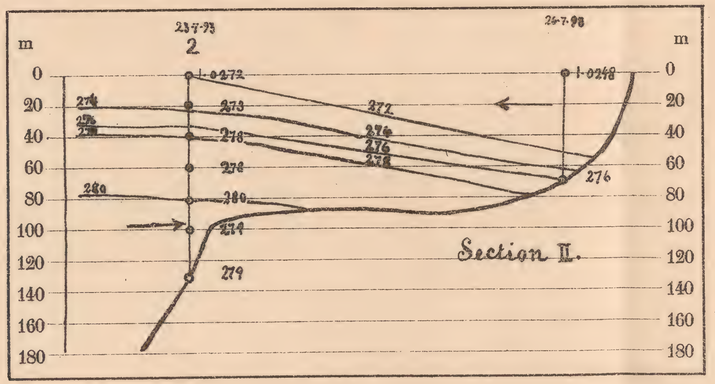
" " Vertical " 1:4000.

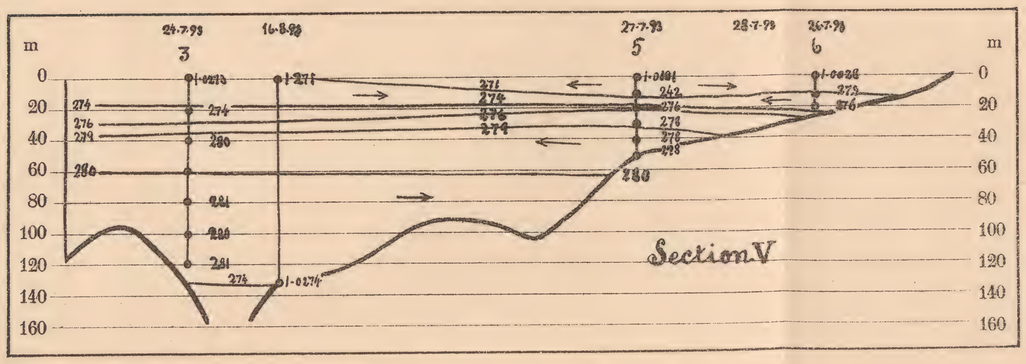
30 40 50 60 70 80 90 100 110 120 180 *Naut Miles.*

40 60 80 100 200 300 *Kilometres.*









SECTIONS from BARENTS SEA.

Jsopyknal.

Vertical Distances 1000 times magnified in proportion to Horizontal Distances.

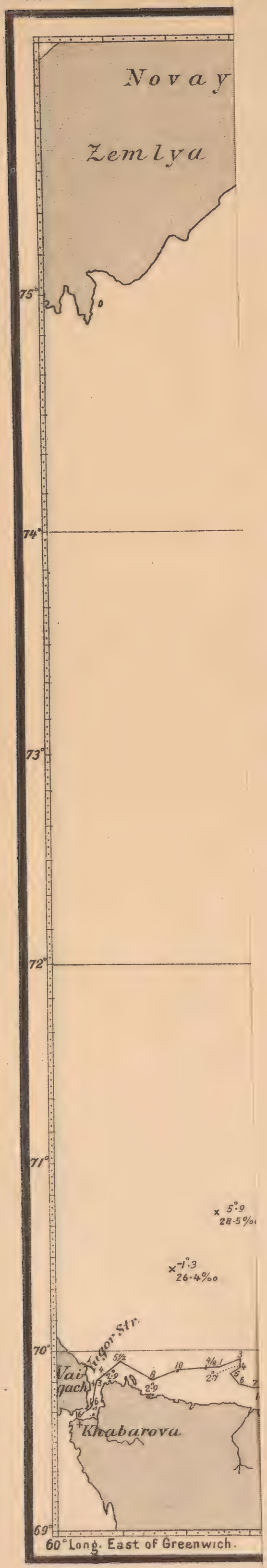
Scale of Horizontal Distances = 1:4,000,000.

" " Vertical " 1: 4000 .

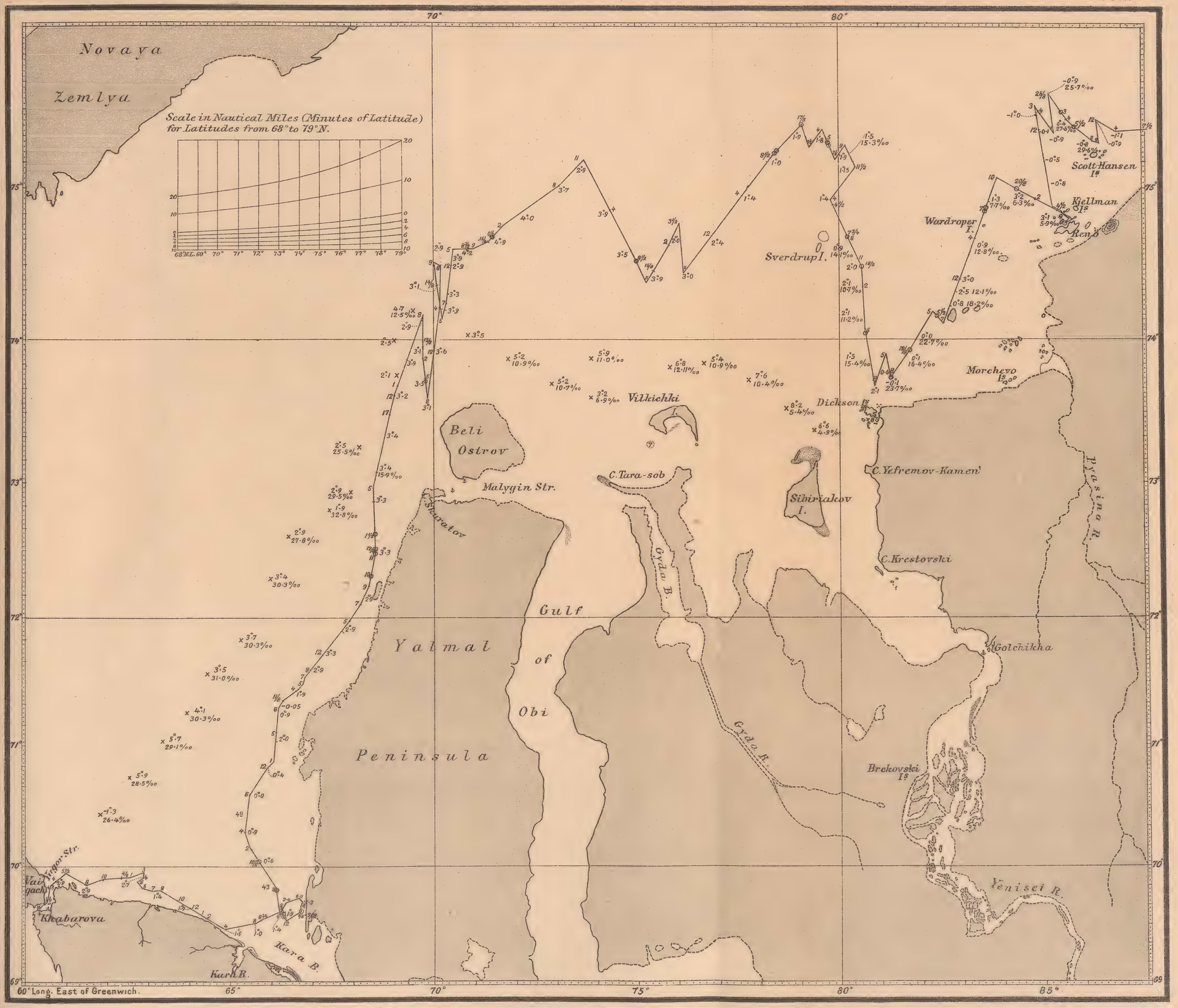
Naut Miles.

Kilometres.

THE NORWEGIAN NORTH



T



TEMPERATURE (°C) AND SALINITY (‰) OF THE SEA-SURFACE ALONG THE FRAM'S TRACK, from Aug. 4 (4/8) to Aug. 25 (25/8), 1893.

The figures along the starbord side of the Fram's track indicate Temperature in Centigrade (0°5) and Salinity in permillage (29·4‰).
The figures along the port side of the Fram's track indicate the Dates (26/8) for every noon, and the Hours (8).
Place determined by astronomical observation.
×0°5 29·4‰ *Observations of Surface Temperature (°C) and Salinity (‰) made during the Vega-Expedition 1878.*

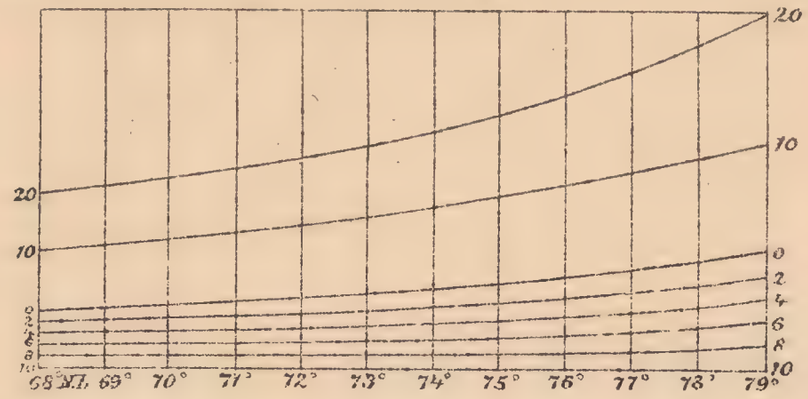
TEMPERATURE (°C) AND SALINITY (‰) OF THE SEA-SURFACE ALONG THE FRAM'S TRACK, from Aug. 26 (26/8) to Sept. 15 (15/9), 1893.

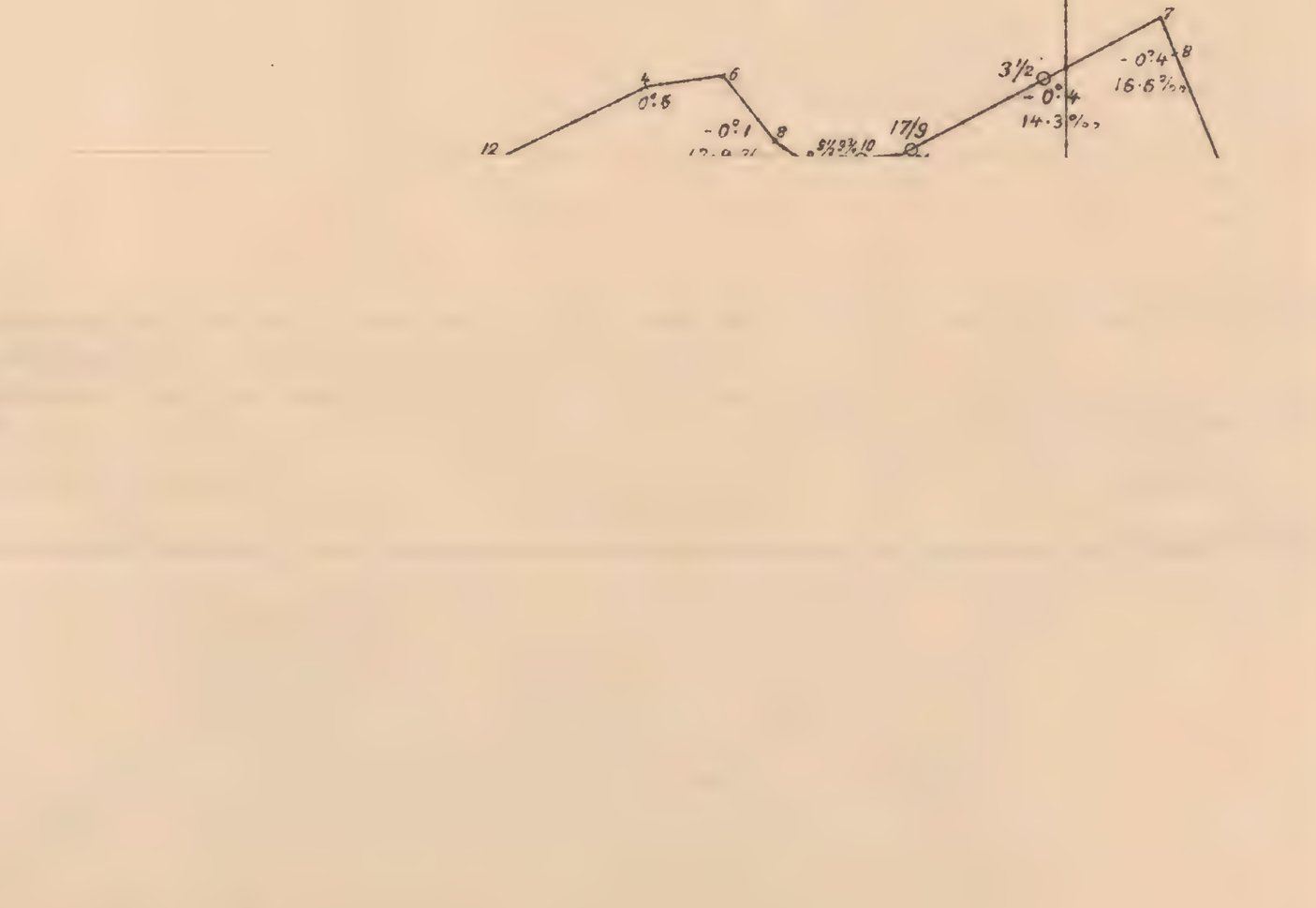
The figures along the starbord side of the Fram's track indicate Temperature in Centigrade (0°.5) and Salinity in permillage (29.4‰).
The figures along the port side of the Fram's track indicate the Dates (26/8) for every noon, and the Hours (8).
Place determined by astronomical observation.
Observations of Surface Temperature (°C) and Salinity (‰) made during the Vega-Expedition 1878.

118° 120° 125° 130°

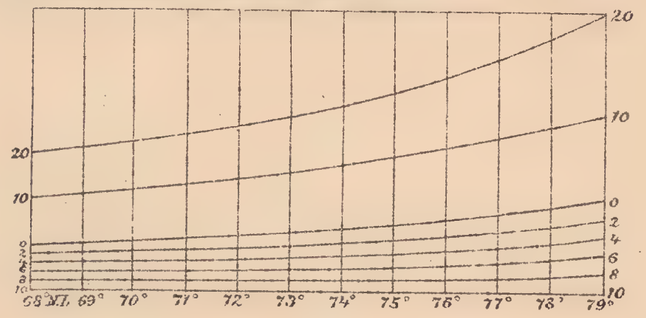
79° 78° 77° 76° 75°

Scale in Nautical Miles (Minuttes of Latitude) for Latitudes from 68° to 79° N.





Scale in Nautical Miles (Minuttes of Latitude) for Latitudes from 68° to 79° N.



Bely-ev I.

Kotel-noi I.

Semenov I.

Vasilyev I.

Stolbovoi I.

Lena

Olenek R.

Western Branch of Lena

Eastern Branch of Lena

118° 120° 125° 130° 135° 140°

79° 78° 77° 76° 75° 74° 73° 72°

117°30' Long. East of Greenwich. 120° 125° 130° 135° 140°

TEMPERATURE (°C) AND SALINITY (‰) OF THE SEA-SURFACE ALONG THE FRAM'S TRACK, from Sept. 15 (15/9) to Sept. 22 (22/9), 1893.

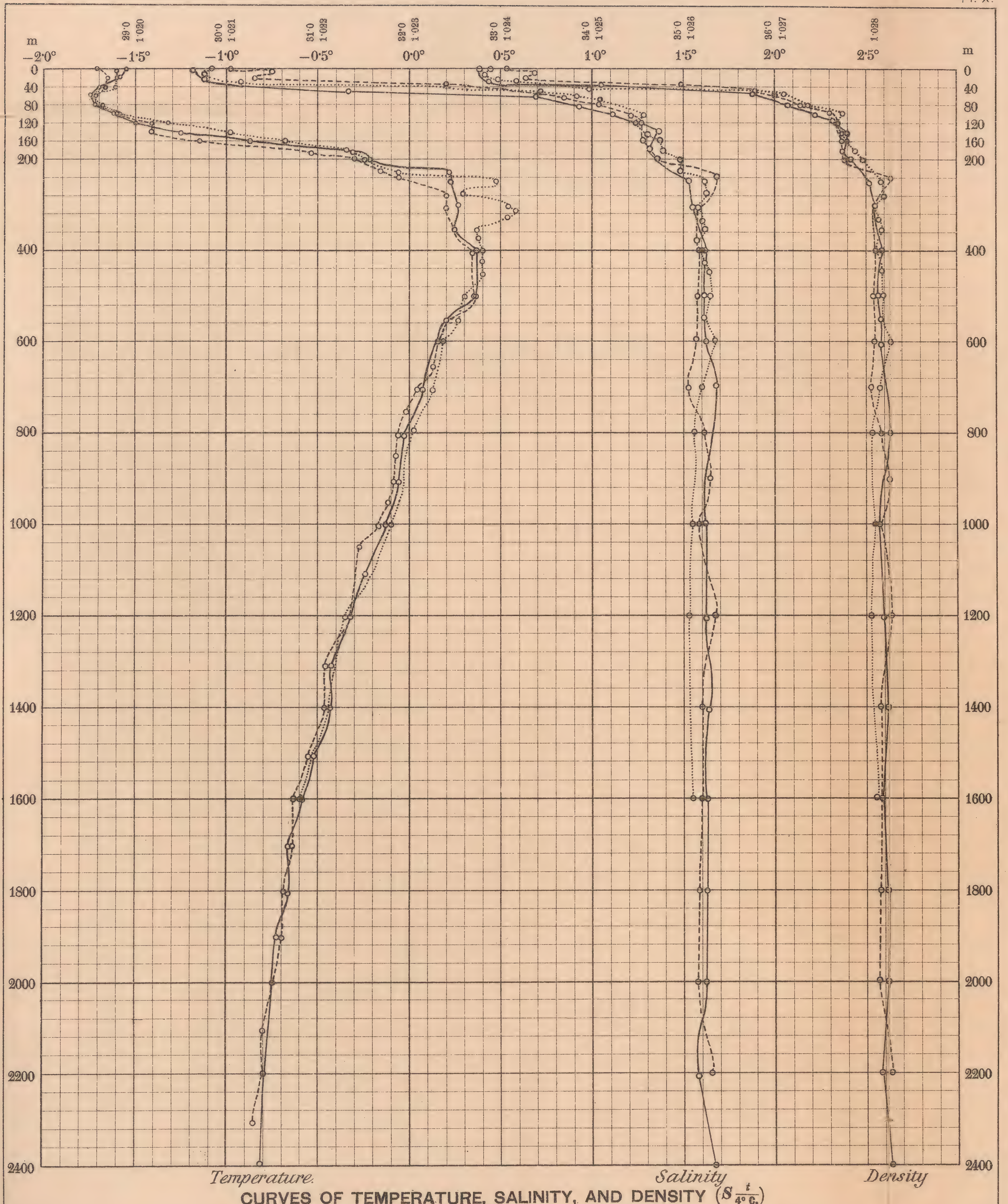
The figures along the starbord side of the Fram's track indicate Temperature in Centigrade (0°5) and Salinity in permillage (29·4‰).
The figures along the port side of the Fram's track indicate the Dates (26/8) for every noon, and the Hours (8).
Place determined by astronomical observation.
Observations of Surface Temperature (°C) and Salinity (‰) made during the Vega-Expedition, 1878.

600
800
1000
1200
1400
1600
1800
2000
2200
2400

Temperature.

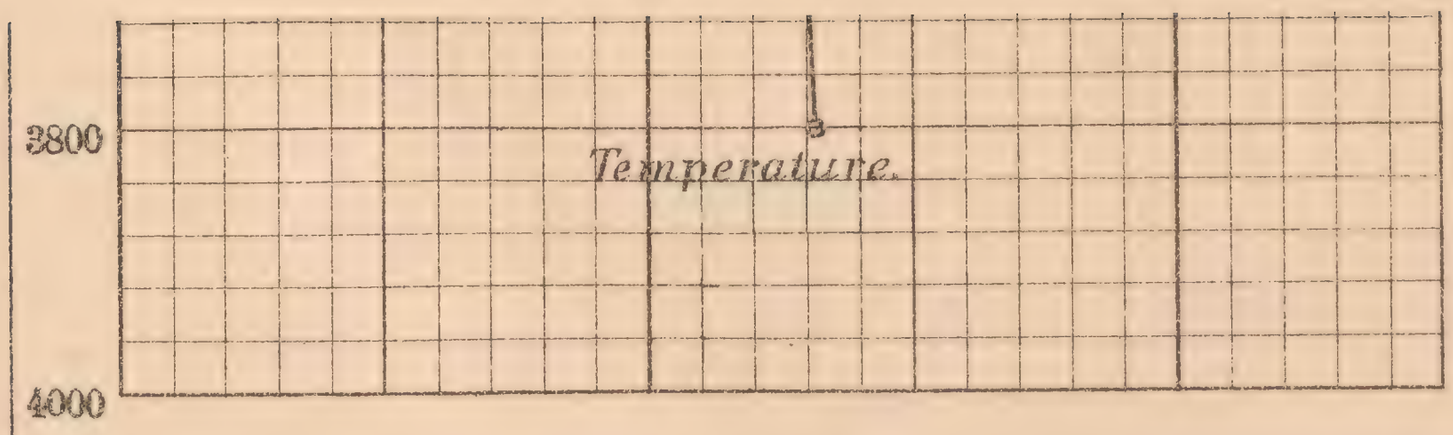
CURVES OF TEMPERATURE, SALINITY, AND

April 1894 ——————— May 1894 – – – – – – –

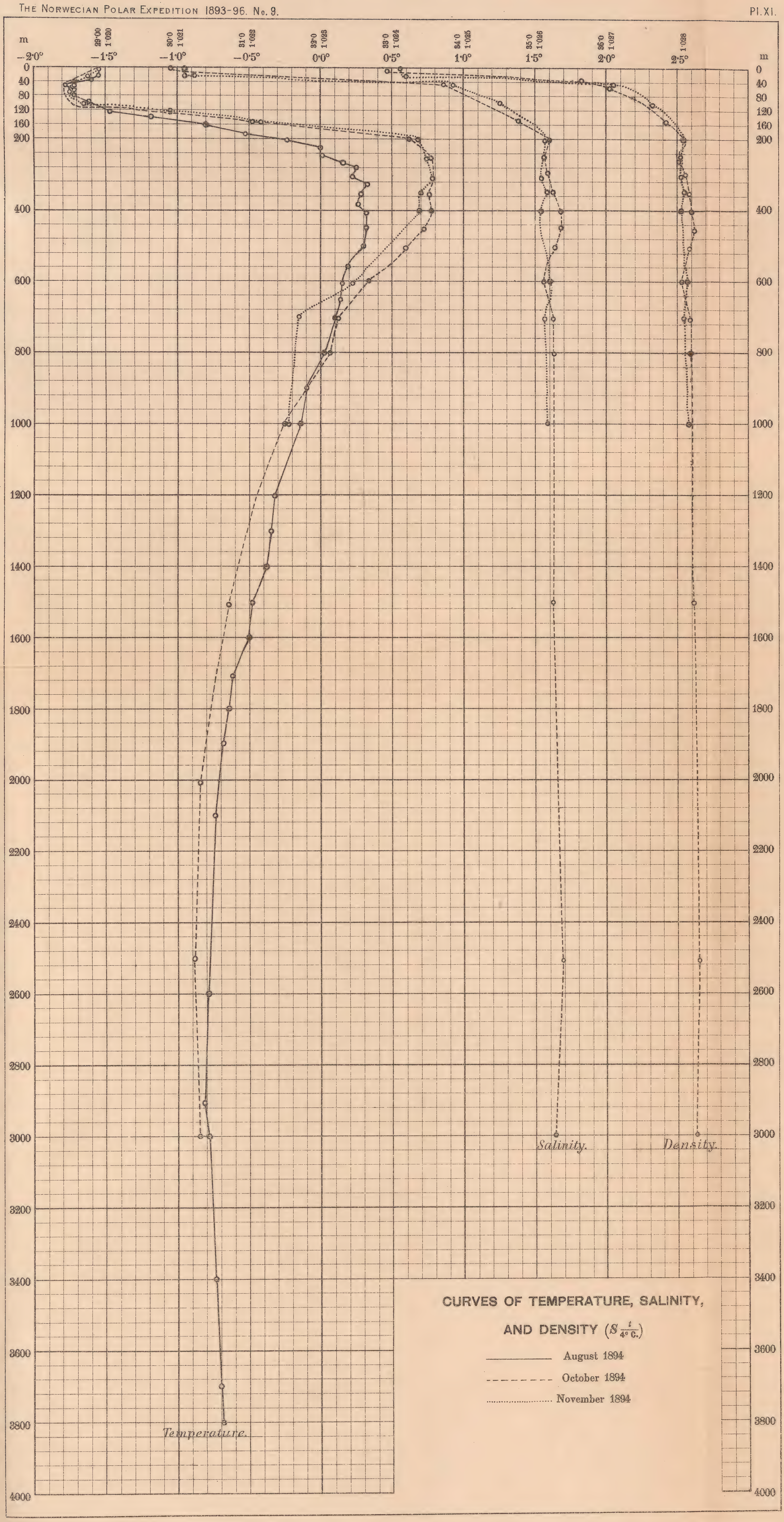


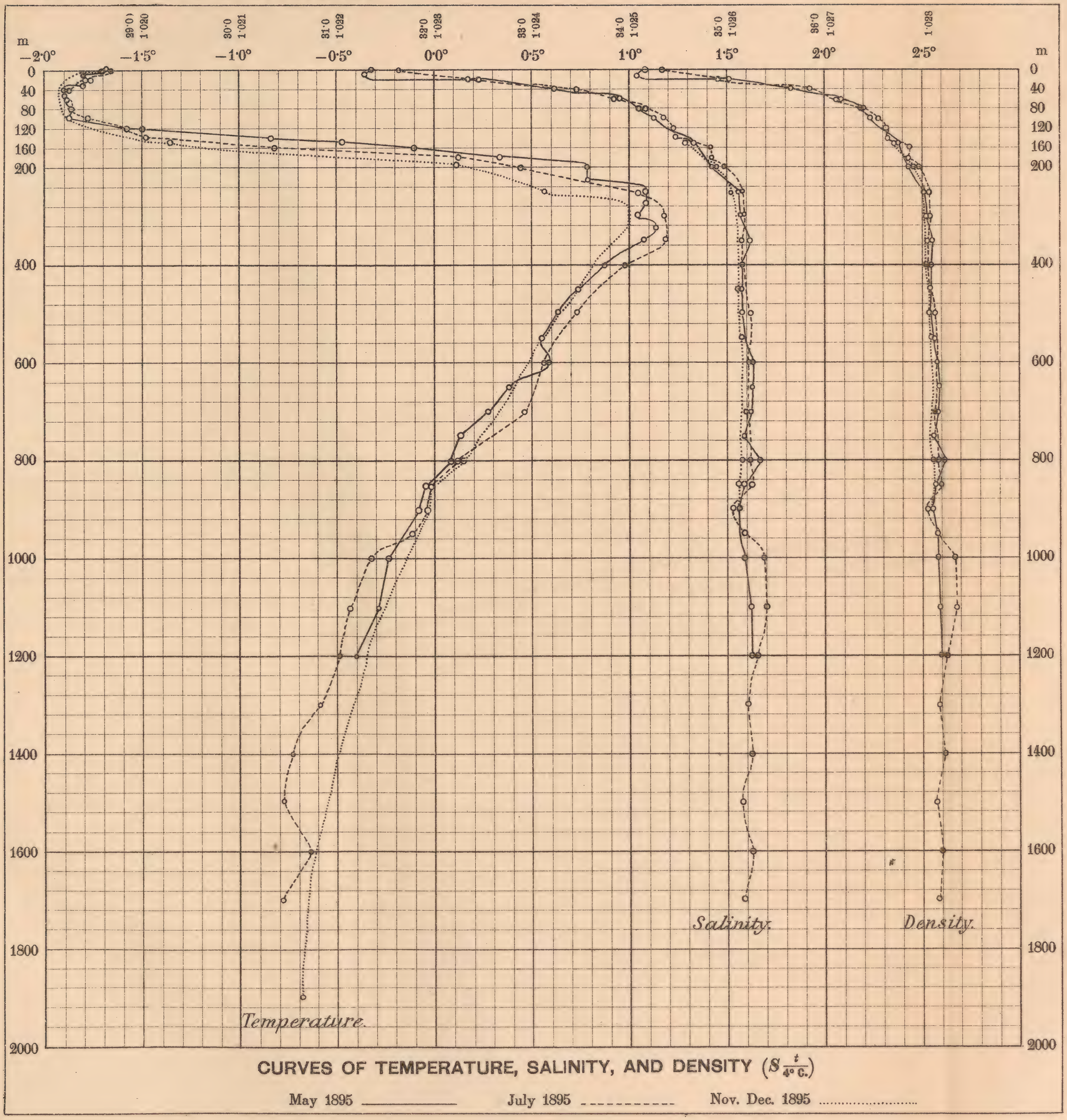
CURVES OF TEMPERATURE, SALINITY, AND DENSITY ($S\frac{t}{4^\circ C.}$)

April 1894 ———— May 1894 – – – – – – – – June 1894 ....



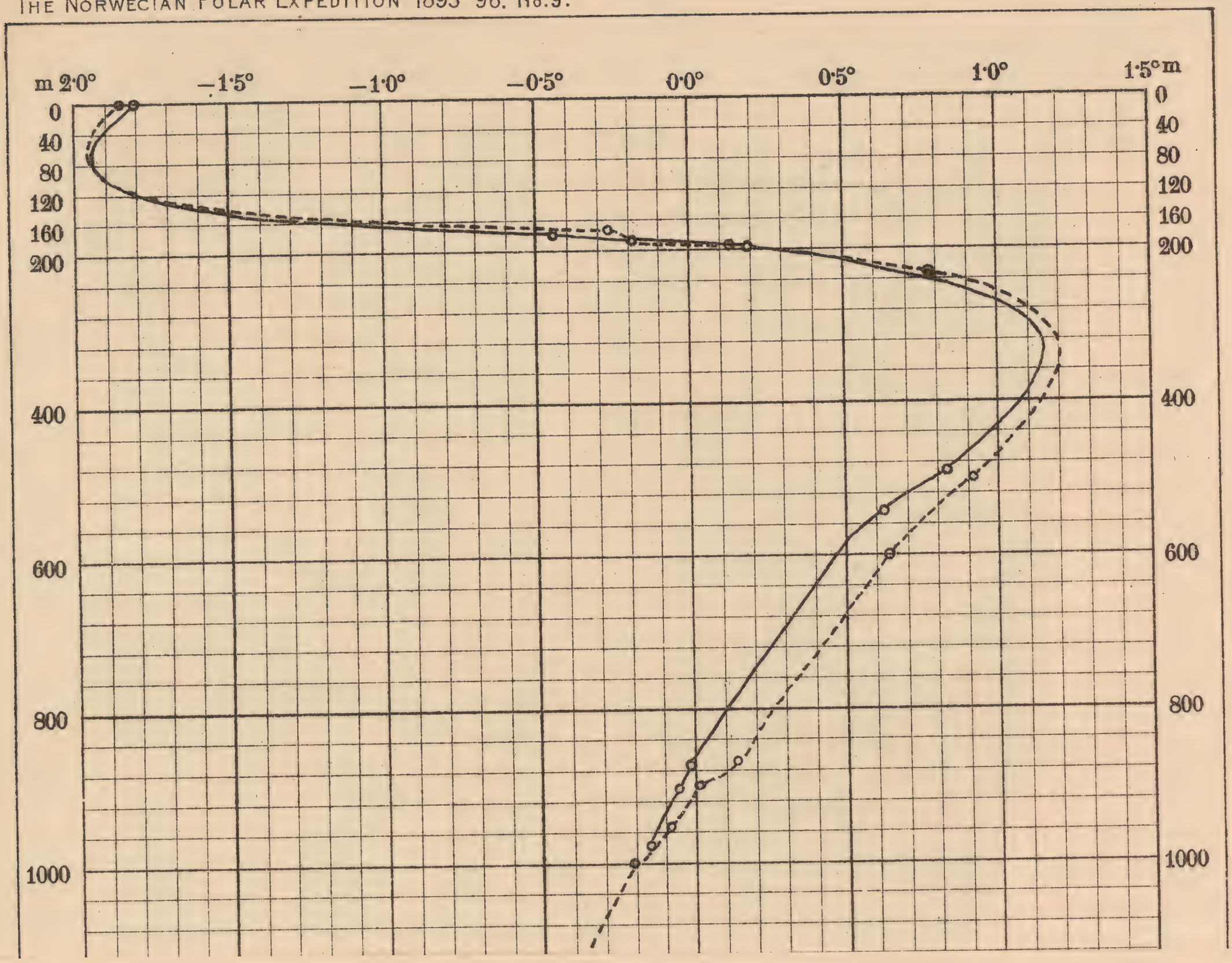
..... No

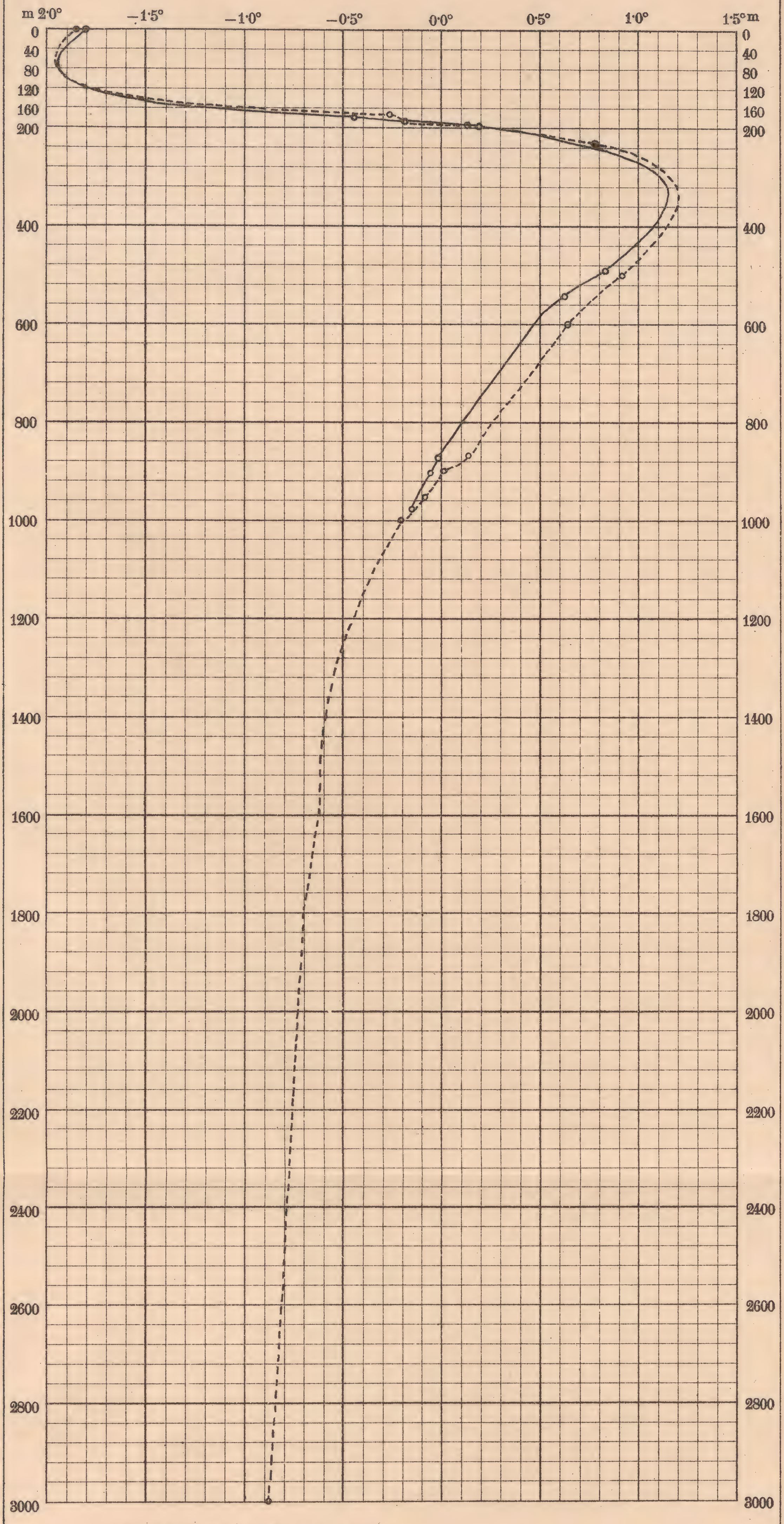

m
28·00 1·020
30·0 1·021
31·0 1·022
32·0 1·023
33·0 1·024
34·0 1·025
35·0 1·026
36·0 1·027
1·028
−2·0°
−1·5°
−1·0°
−0·5°
0·0°
0·5°
1·0°
1·5°
2·0°
2·5°
m
0
40
80
120
160
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
Salinity.
Density.
Temperature.
CURVES OF TEMPERATURE, SALINITY,
AND DENSITY ($S\frac{t}{4^\circ C.}$)
August 1894
October 1894
November 1894



CURVES OF TEMPERATURE, SALINITY, AND DENSITY ($S\frac{t}{4^\circ C.}$)

May 1895 _____ July 1895 - - - - - - - - - - Nov. Dec. 1895 .....


m 2·0°
−1·5°
−1·0°
−0·5°
0·0°
0·5°
1·0°
1·5° m
0
40
80
120
160
200
400
600
800
1000



CURVES OF TEMPERATURE.

February 1896. ———— April 1896. - - - - - - - -

June 94 | May 94 | July 94 | Aug. 94 | Apr. 94 | March 94 | Dec. 93 | Oct. 93 | Oct. 93 | Nov. 93

16 | 15 | 17 | 18 | 14 | 13 | 12 | 8 | 9 | 11

m

0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700 3800 3900 4000

0° 35‰ 35·1‰ 35·2‰

33‰ 34·034 ‰

TH POLAR BASIN
AM'S Route.

Isohaline.

magnified in stances.

nces = 1:4,000,000.
1: 20,000.

180 Naut. Miles.
300 Kilometres.

Below 30·0 ‰

30·0 – 32·0 ‰

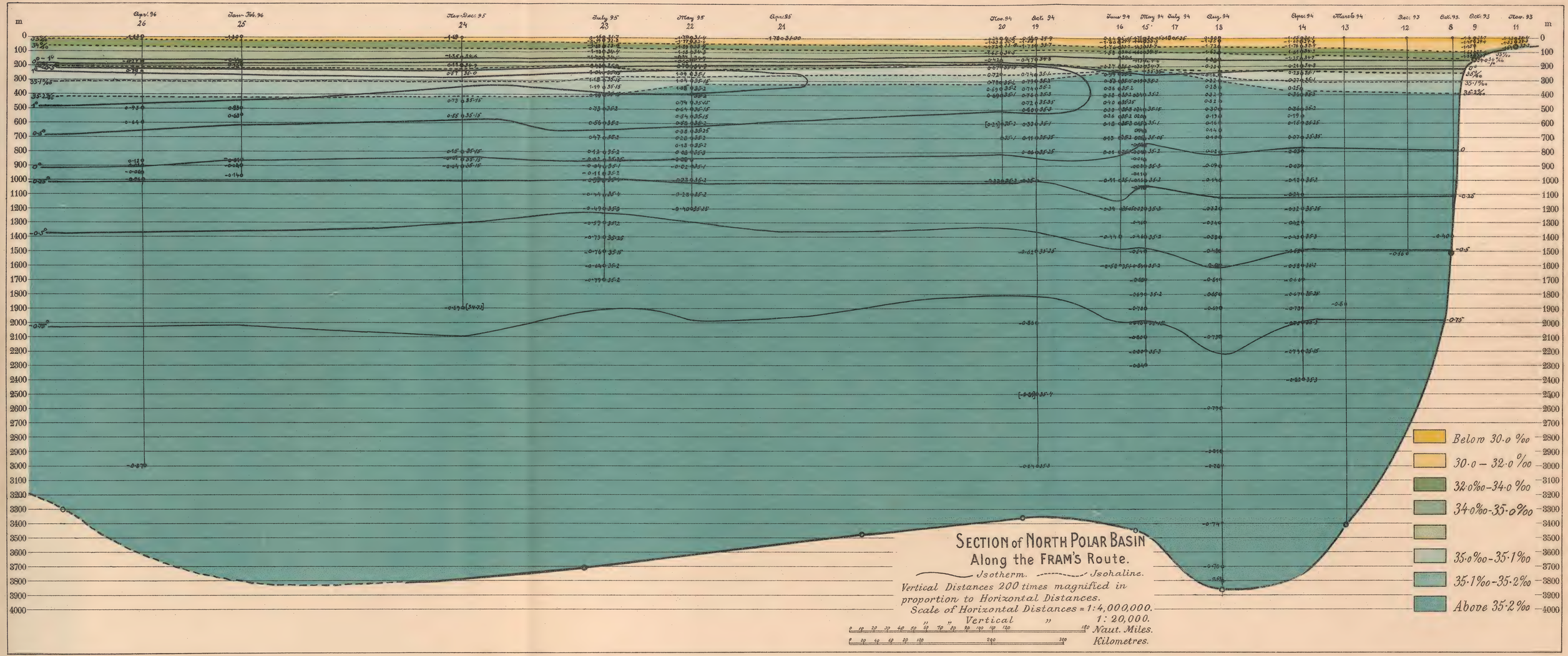
32·0‰–34·0 ‰

34·0‰-35·0‰

35·0‰-35·1‰

35·1‰-35·2‰

Above 35·2‰



SECTION of NORTH POLAR BASIN
Along the FRAM'S Route.

Isotherm. ---------- Isohaline.

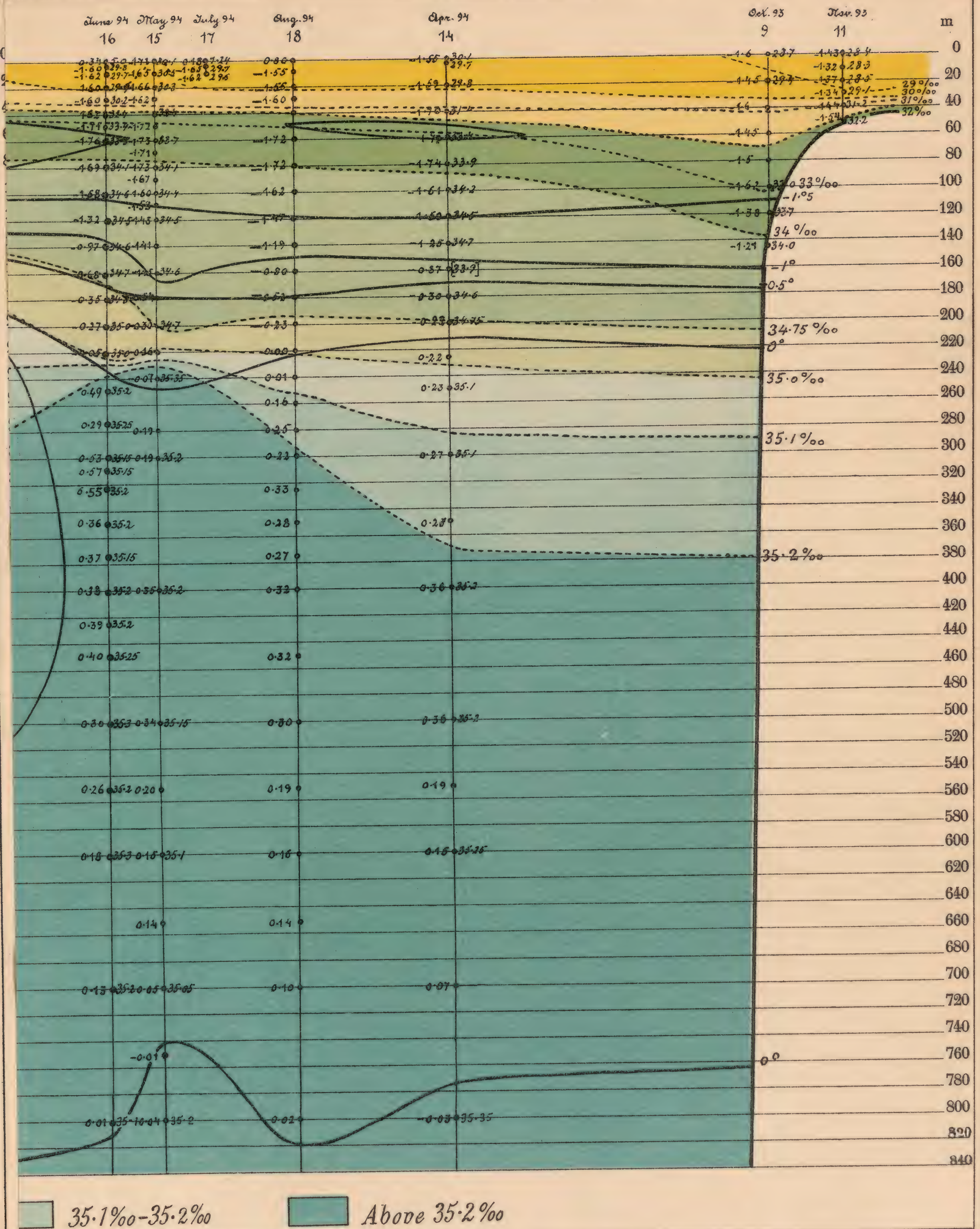
Vertical Distances 200 times magnified in proportion to Horizontal Distances.

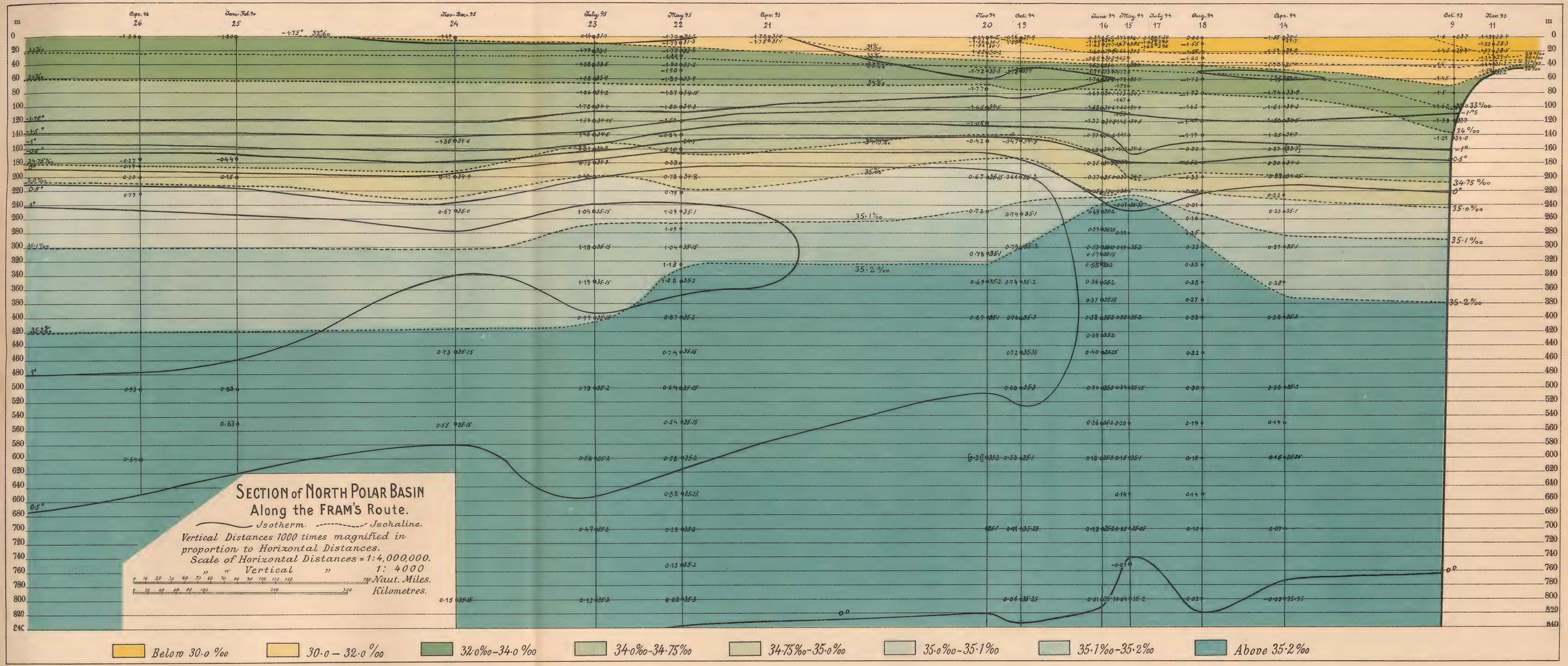
Scale of Horizontal Distances = 1:4,000,000.

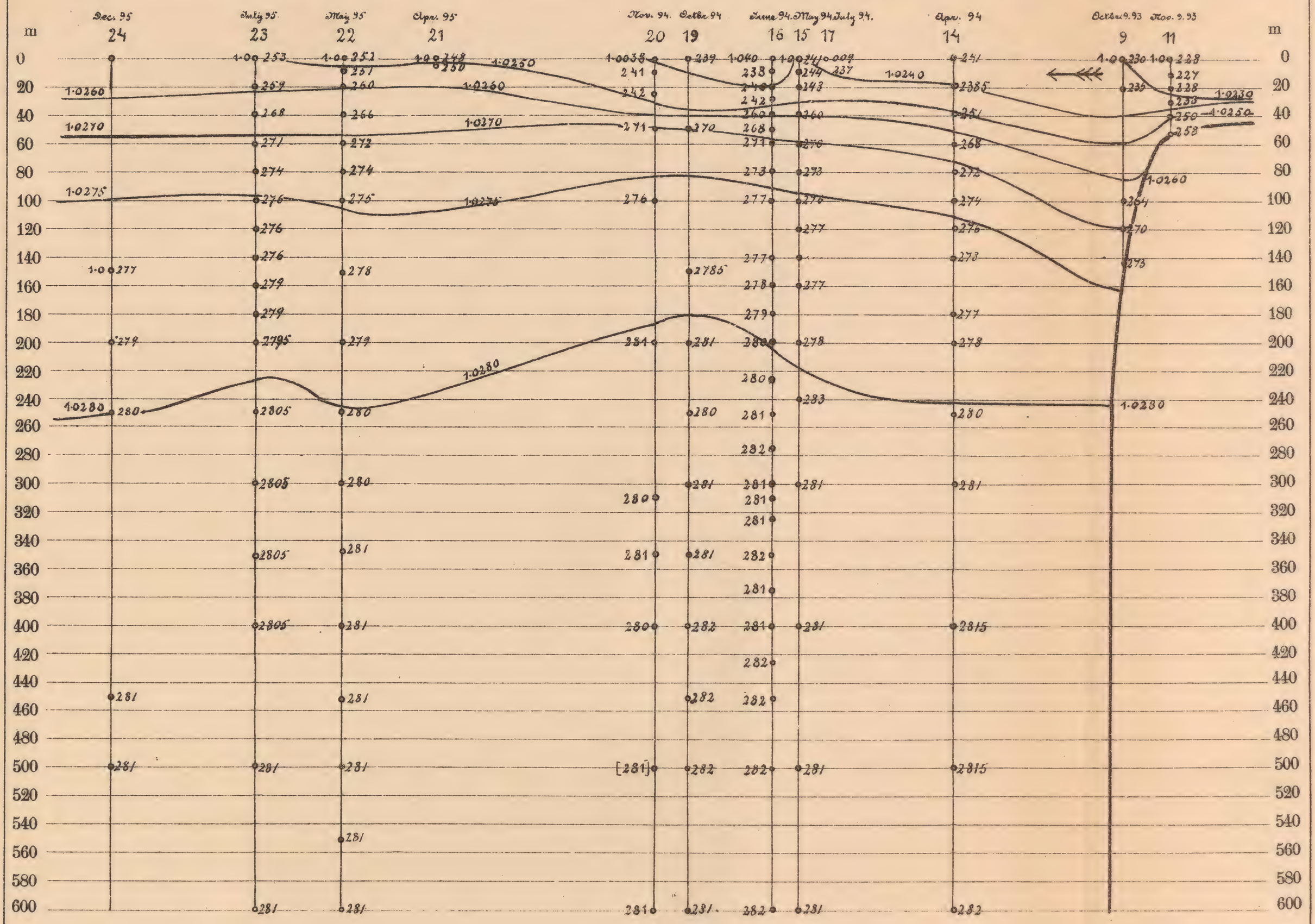
" Vertical " 1: 20,000.

0 10 20 30 40 50 60 70 80 90 100 110 120 140 Naut. Miles.

0 20 40 60 80 100 200 300 Kilometres.


June 94
16
May 94
15
July 94
17
Aug. 94
18
Apr. 94
14
Oct. 93
9
Nov. 93
11
m
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
740
760
780
800
820
840
29 ‰
30 ‰
31 ‰
32 ‰
33 ‰
34 ‰
34.75 ‰
35.0 ‰
35.1 ‰
35.2 ‰
-1.05
-1°
0.5°
0°
0°
35.1‰-35.2‰
Above 35.2‰


Apr. 96
26
Nov.-Feb. 96
25
Nov.-Dec. 95
24
July 95
23
May 95
22
Apr. 95
21
Nov 94
20
Oct. 94
19
June 94
16
May 94
15
July 94
17
Aug. 94
18
Apr. 94
14
Oct. 93
9
Nov. 93
11
m
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
740
760
780
800
820
840
34·75 ‰
35·0 ‰
35·1 ‰
35·2 ‰
SECTION of NORTH POLAR BASIN
Along the FRAM's Route.
Isotherm.
Isohaline.
Vertical Distances 1000 times magnified in proportion to Horizontal Distances.
Scale of Horizontal Distances = 1:4,000,000.
" " Vertical " 1: 4000
Naut. Miles.
Kilometres.
Below 30·0 ‰
30·0 – 32·0 ‰
32·0‰-34·0 ‰
34·0‰-34·75‰
34·75‰-35·0‰
35·0‰-35·1‰
35·1‰-35·2‰
Above 35·2‰



SECTION of NORTH POLAR BASIN
Along the FRAM'S Route.

~ *Isopyknal.*

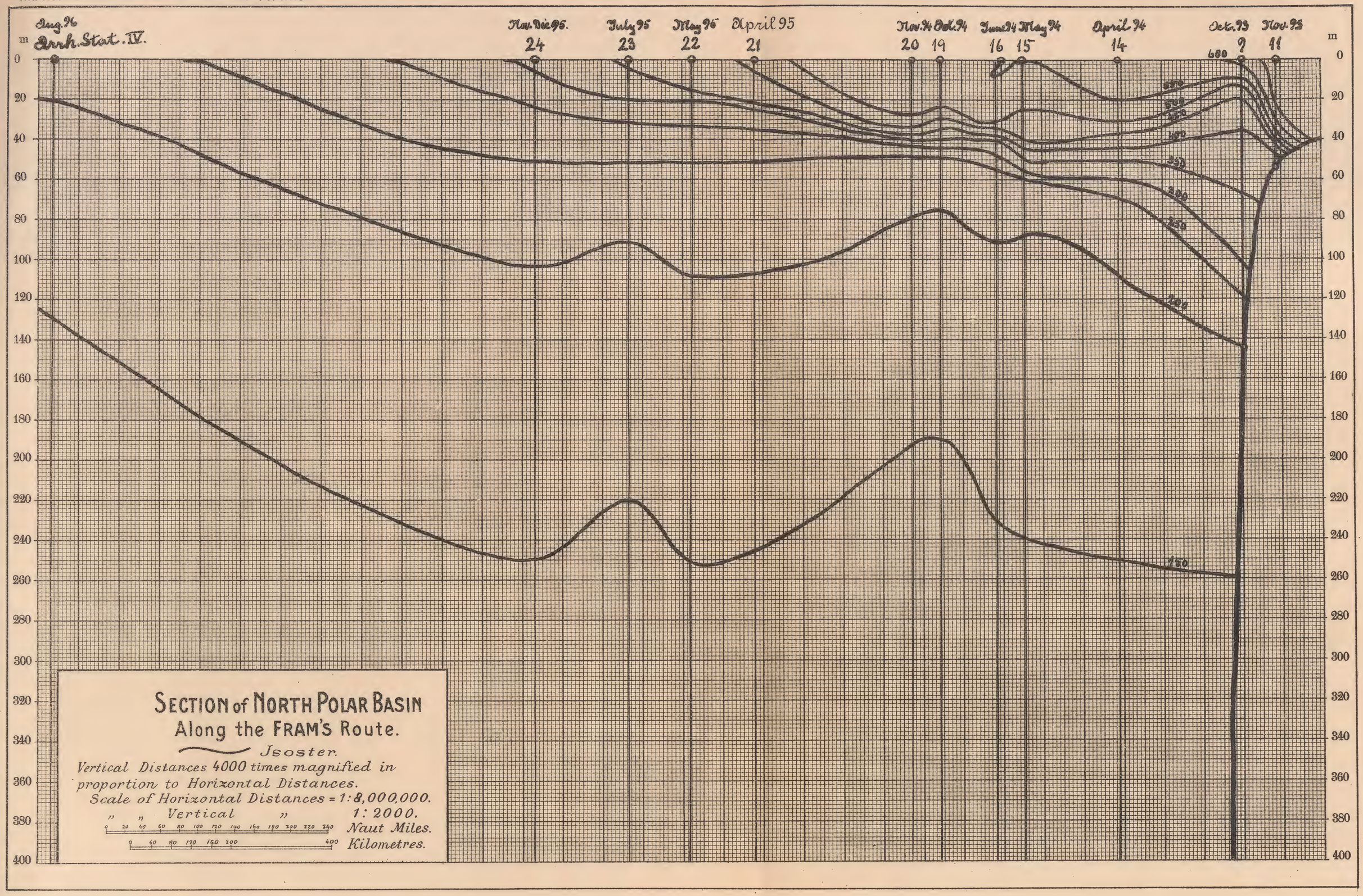
Vertical Distances 2000 times magnified in proportion to Horixontal Distances.

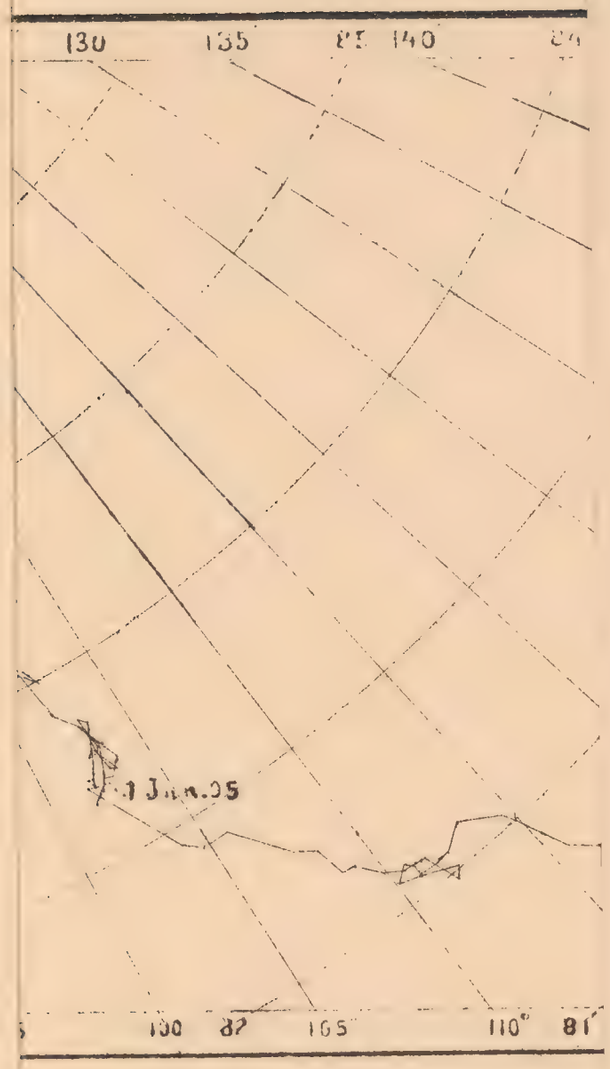
Scale of Horizontal Distances = 1:8,000,000.

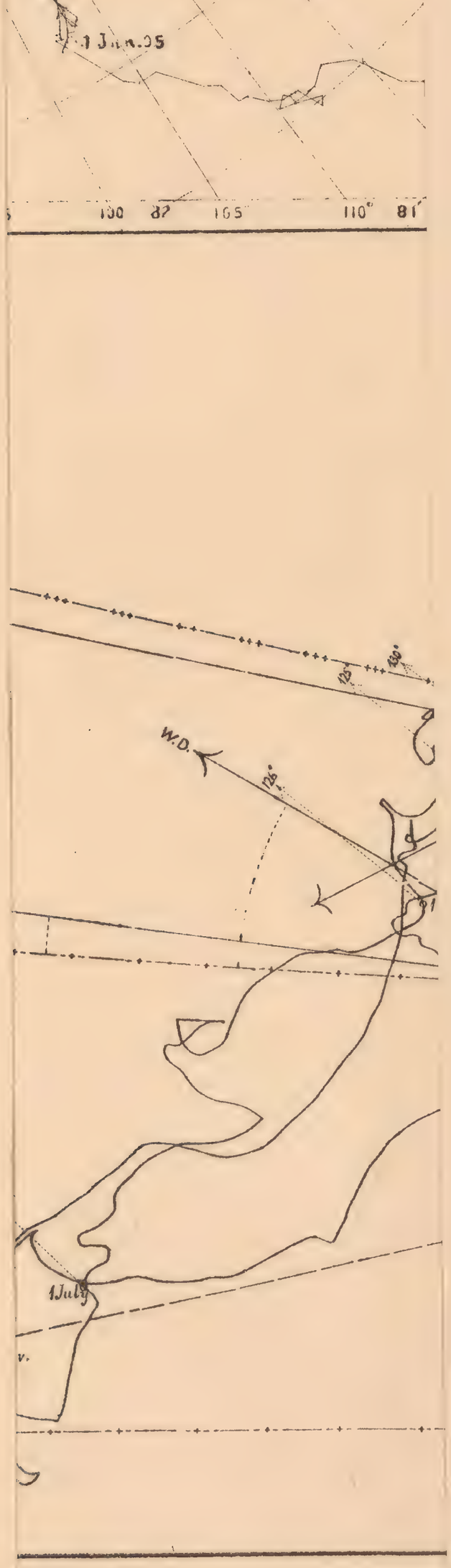
„ „ Vertical „ 1:40000.

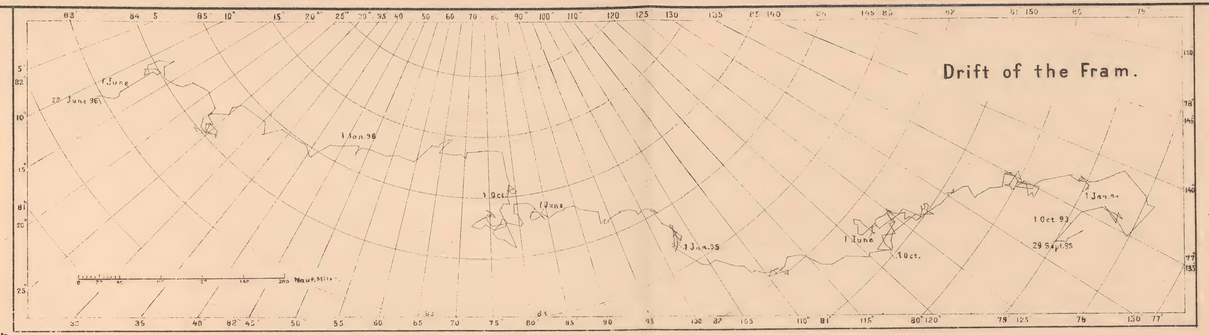
0 20 40 60 80 100 120 140 150 180 200 220 240 *Naut Miles.*

0 40 80 120 160 200 400 *Kilometres.*


Aug. 96
Arrh. Stat. IV.
Nov. Dec. 95.
24
July 95
23
May 95
22
April 95
21
Nov. 94
20
Oct. 94
19
June 94
16
May 94
15
April 94
14
Oct. 93
9
Nov. 93
11
m
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
600
550
500
450
400
350
300
250
200
150
SECTION of NORTH POLAR BASIN
Along the FRAM'S Route.
Jsoster.
Vertical Distances 4000 times magnified in proportion to Horizontal Distances.
Scale of Horizontal Distances = 1:8,000,000.
" " Vertical " 1:2000.
0 20 40 60 80 100 120 140 160 180 200 220 240 Naut Miles.
0 40 80 120 160 200 400 Kilometres.


130
135
140
1 Jan.05
100
105
110°


W.D.
1July
v.



The Winds along the Frams Track from September 29, 1893, to June 28, 1896.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North. The Figure at the End of the Arrow indicates Longitude east of Greenwich. The Figures along the Curve indicate Civil Date at 0 h. m.

Winter-Resultants of the Wind.

Year-Resultants of the Wind.

Resultant of the Wind during the whole Drift.

Resultants of the Drift.

W.D. Resultants of the Drift produced by the Wind.

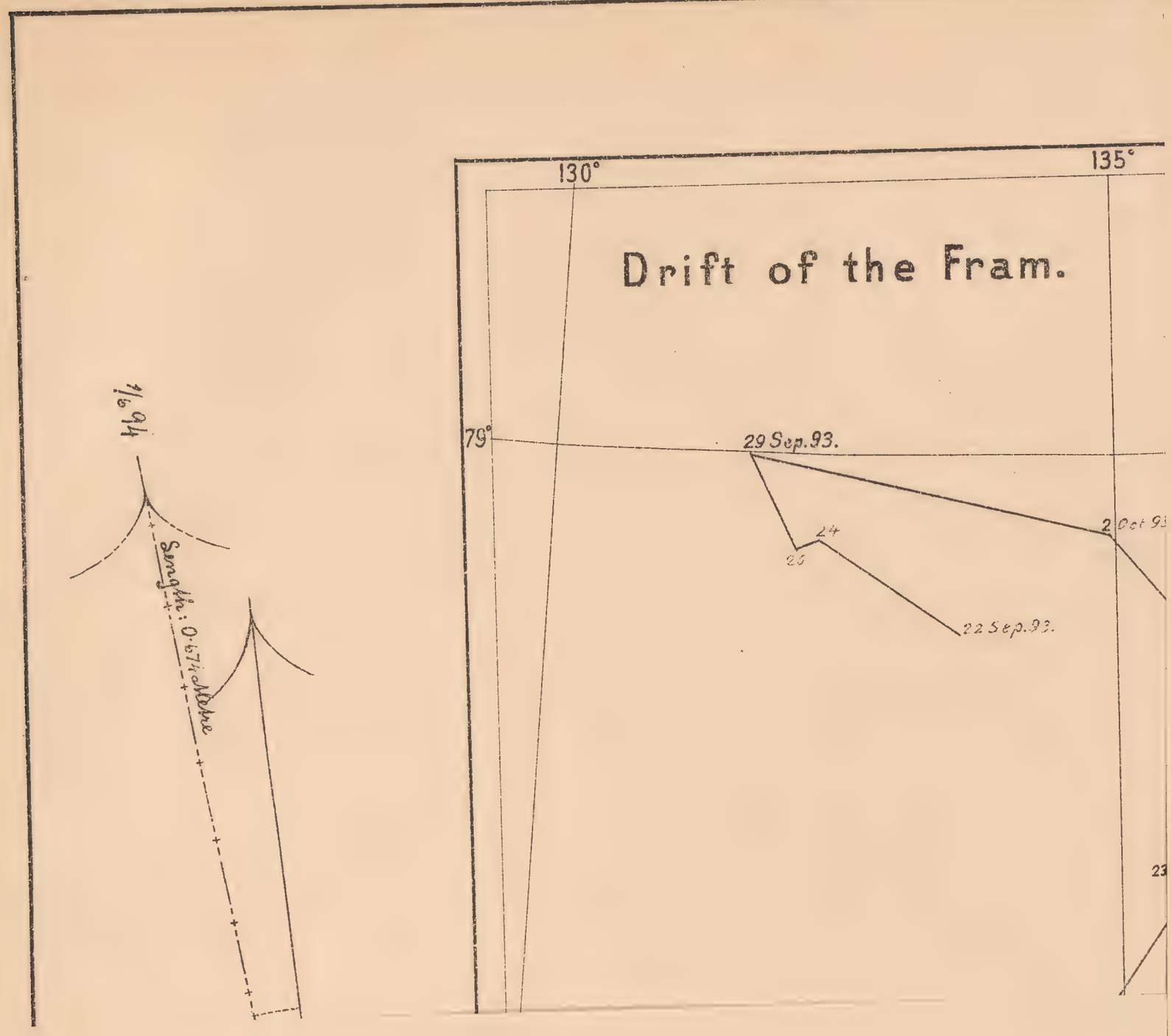
Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

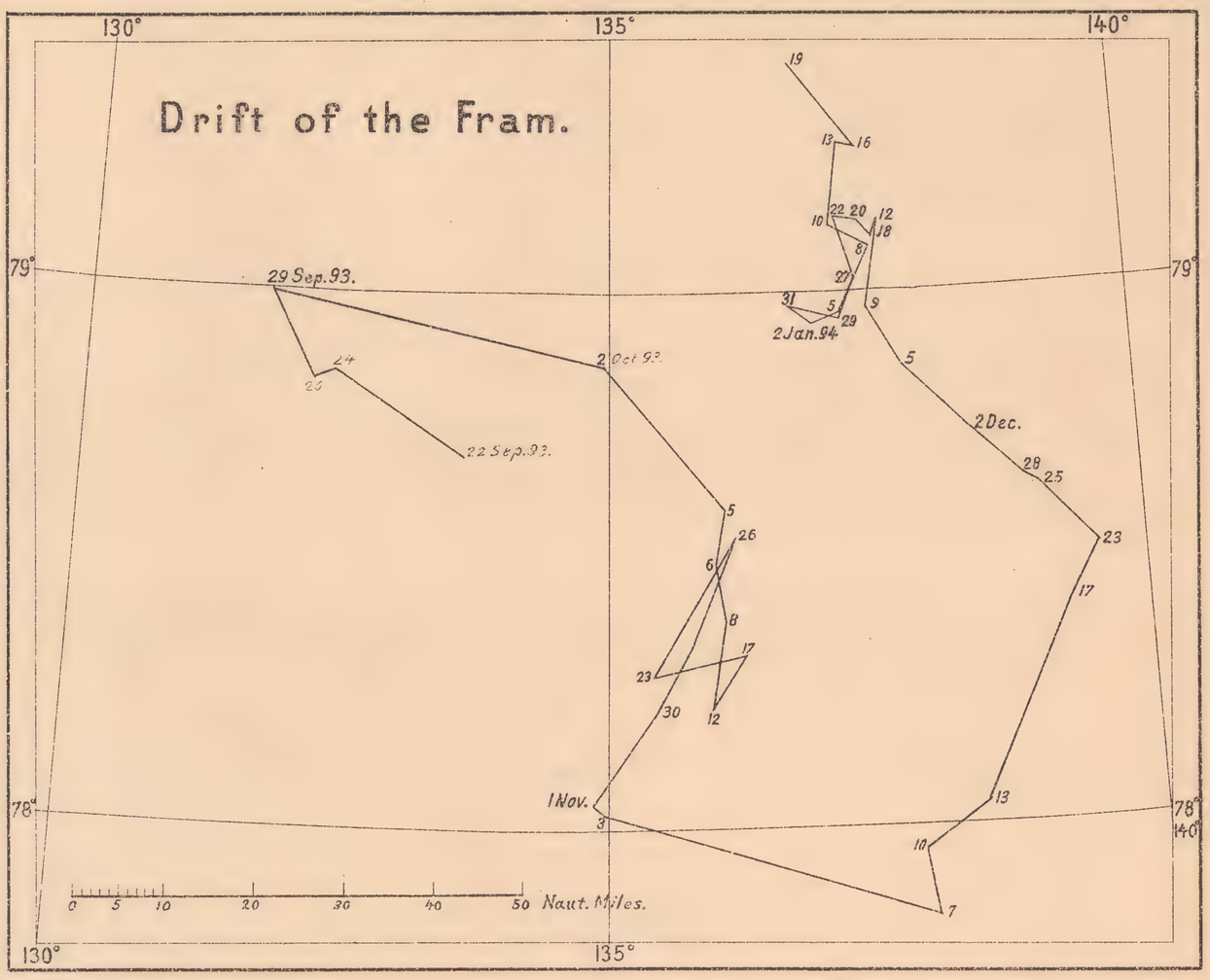
Scale.

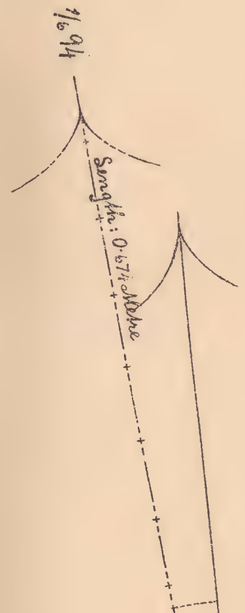
1 mm. of the Wind-Lines = 8 Metres velocity of the Wind.

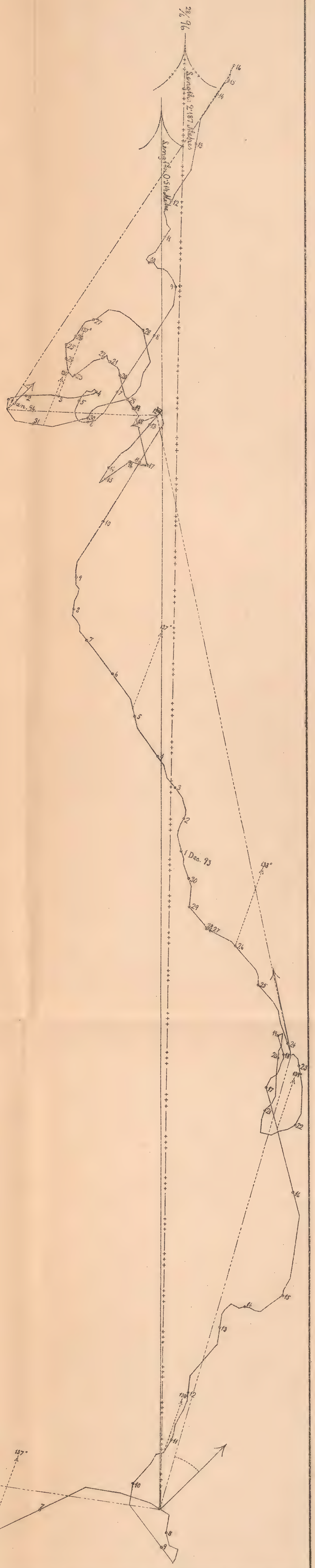
1 mm. of the Drift-Resultants = 4 Nautical Miles.

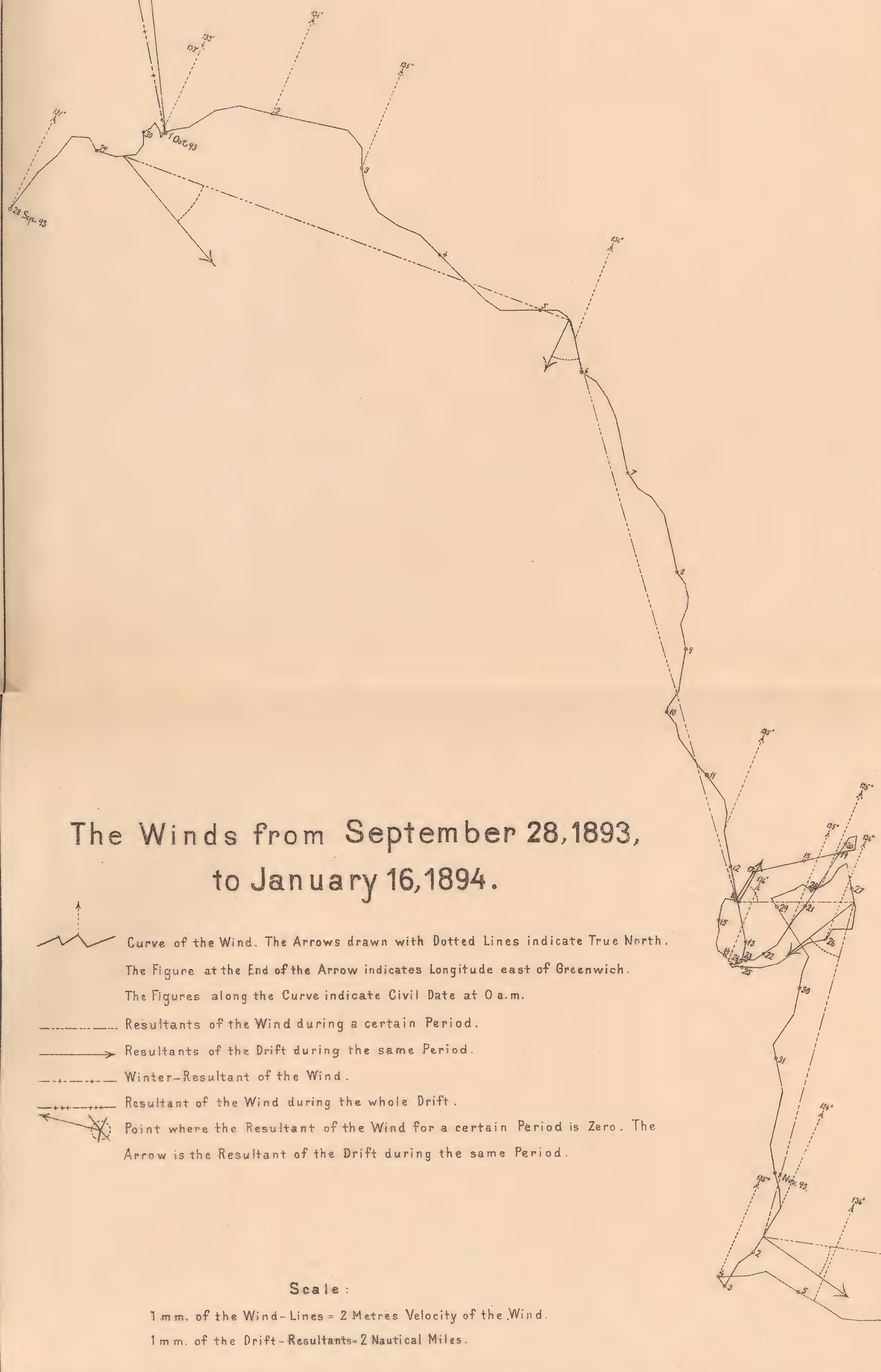
Kerting lith. Kra.


Drift of the Fram.
130°
135°
79°
29 Sep. 93.
24
23
22 Sep. 93.
2 Oct 93
23
Length: 0.67 Statute
Length: 0.67 Statute









The Winds from September 28, 1893, to January 16, 1894.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.

The Figure at the End of the Arrow indicates Longitude east of Greenwich.

The Figures along the Curve indicate Civil Date at 0 a.m.

Resultants of the Wind during a certain Period.

Resultants of the Drift during the same Period.

Winter-Resultant of the Wind.

Resultant of the Wind during the whole Drift.

Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

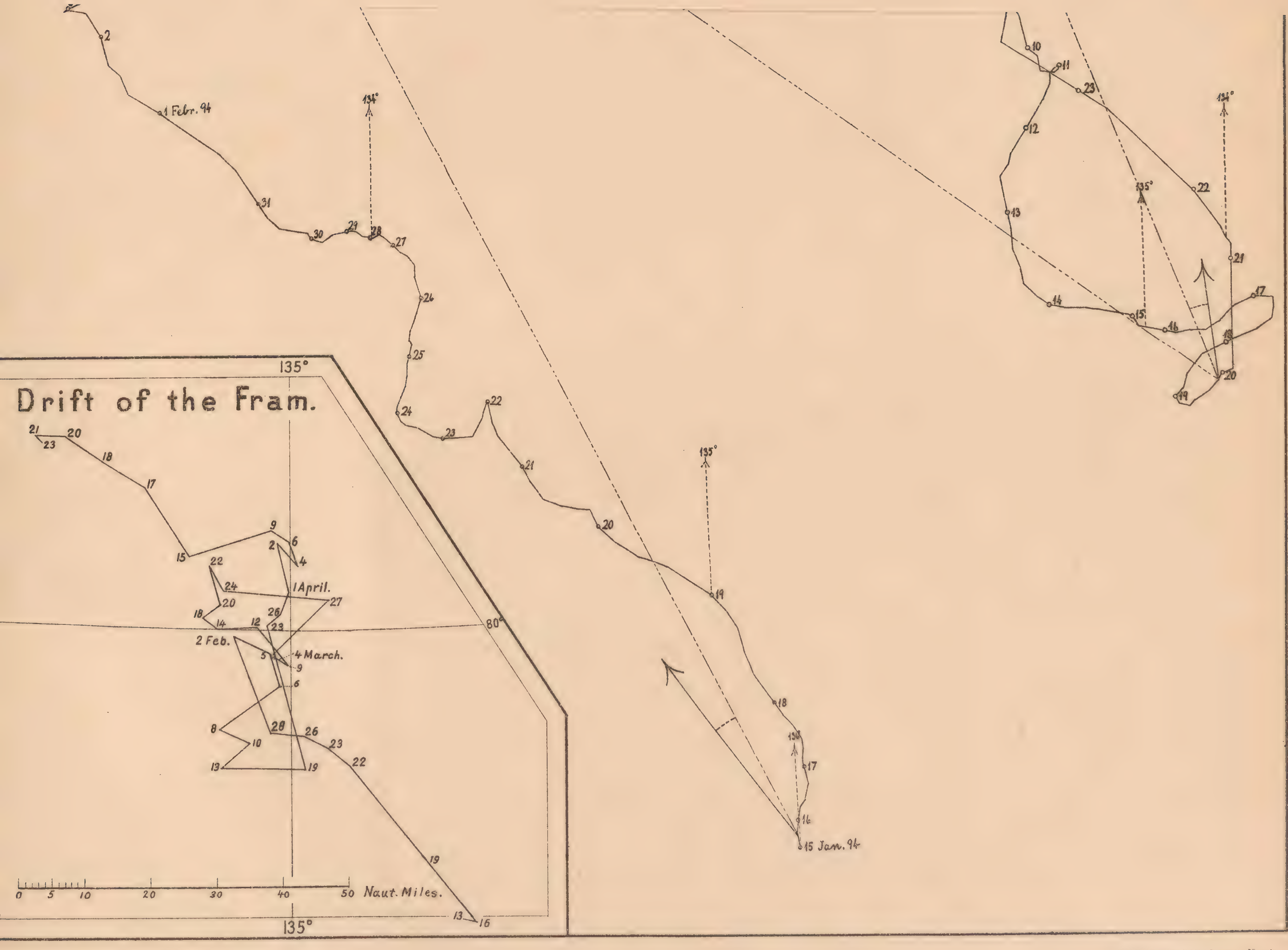
Scale:

1 m m. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 m m. of the Drift-Resultants = 2 Nautical Miles.

Kart-og Litografering skontoret, Kr ania.

Drift of the Fram.



Kart-og Litograferingskontoret, Kristiania.

The Winds from January 15, 1894, to April 22, 1894.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.

The Figure at the End of the Arrow indicates Longitude east of Greenwich.

The Figures along the Curve indicate Civil Date at 0 a.m.

Resultants of the Wind during a certain Period.

Resultants of the Drift during the same Period.

Winter-Resultant of the Wind.

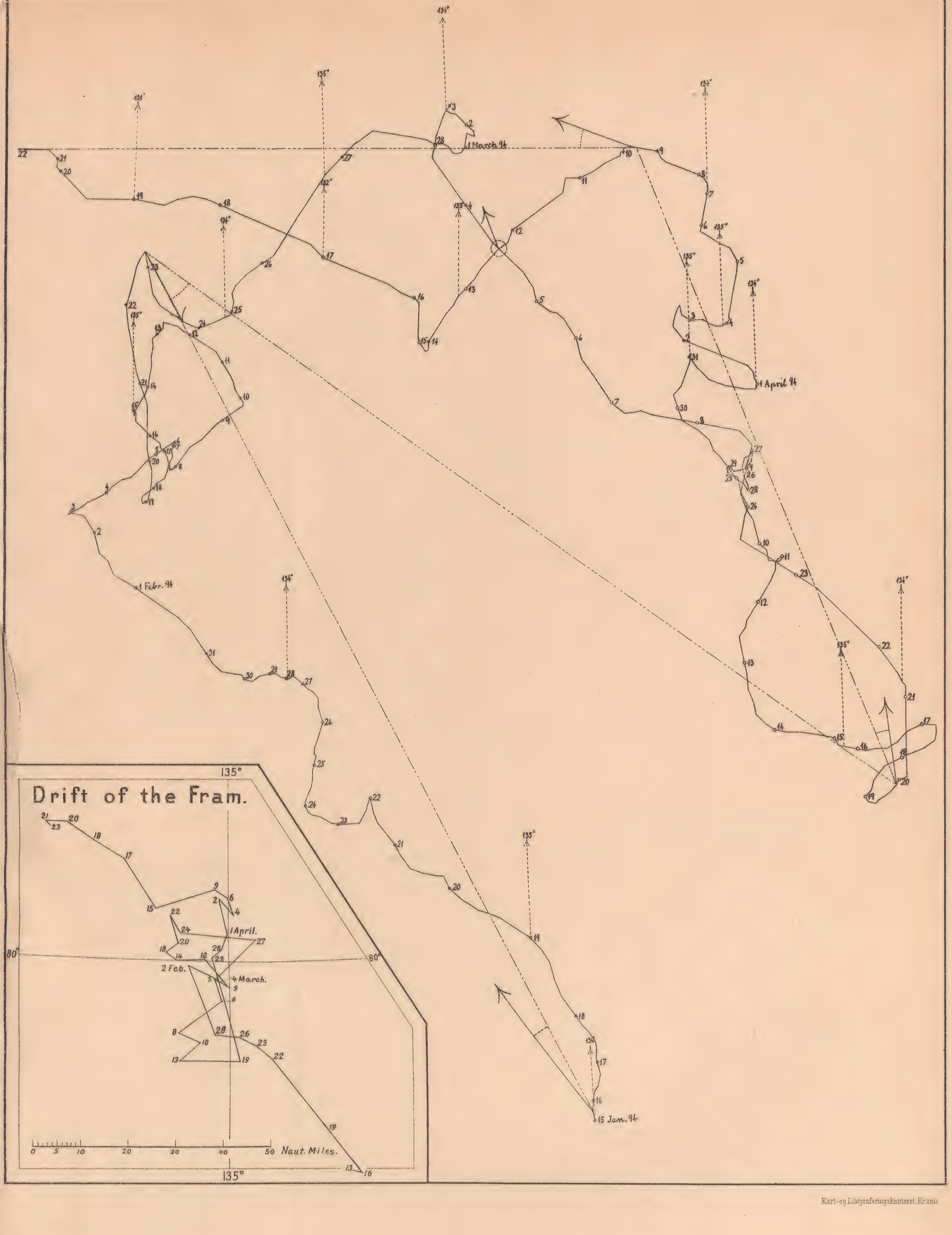
Resultant of the Wind during the whole Drift.

Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

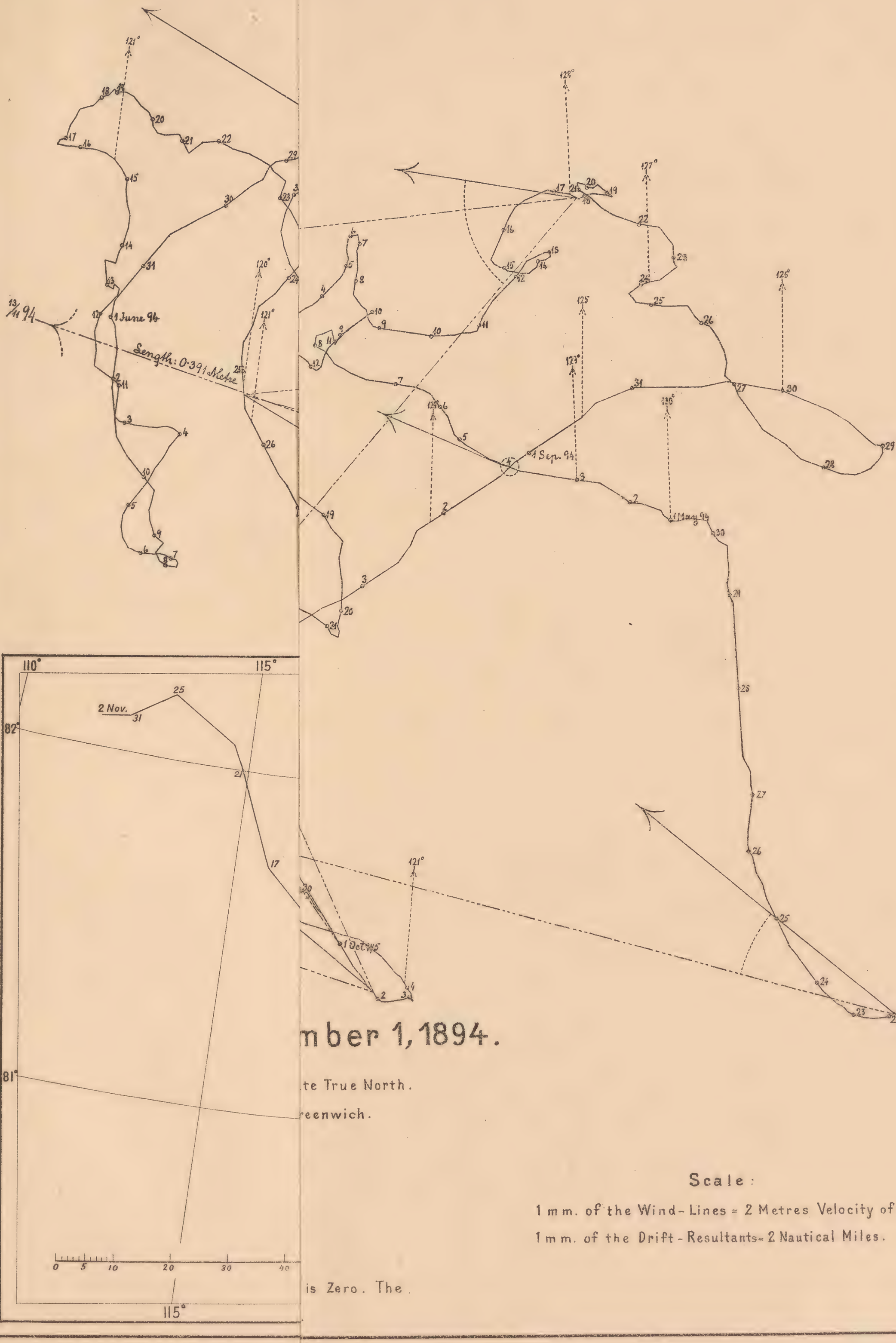
Scale:

1 mm. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 mm. of the Drift-Resultants = 2 Nautical Miles.



Kart-og Litograferingskontoret, Kr.ania



mber 1, 1894.

te True North.

eenwich.

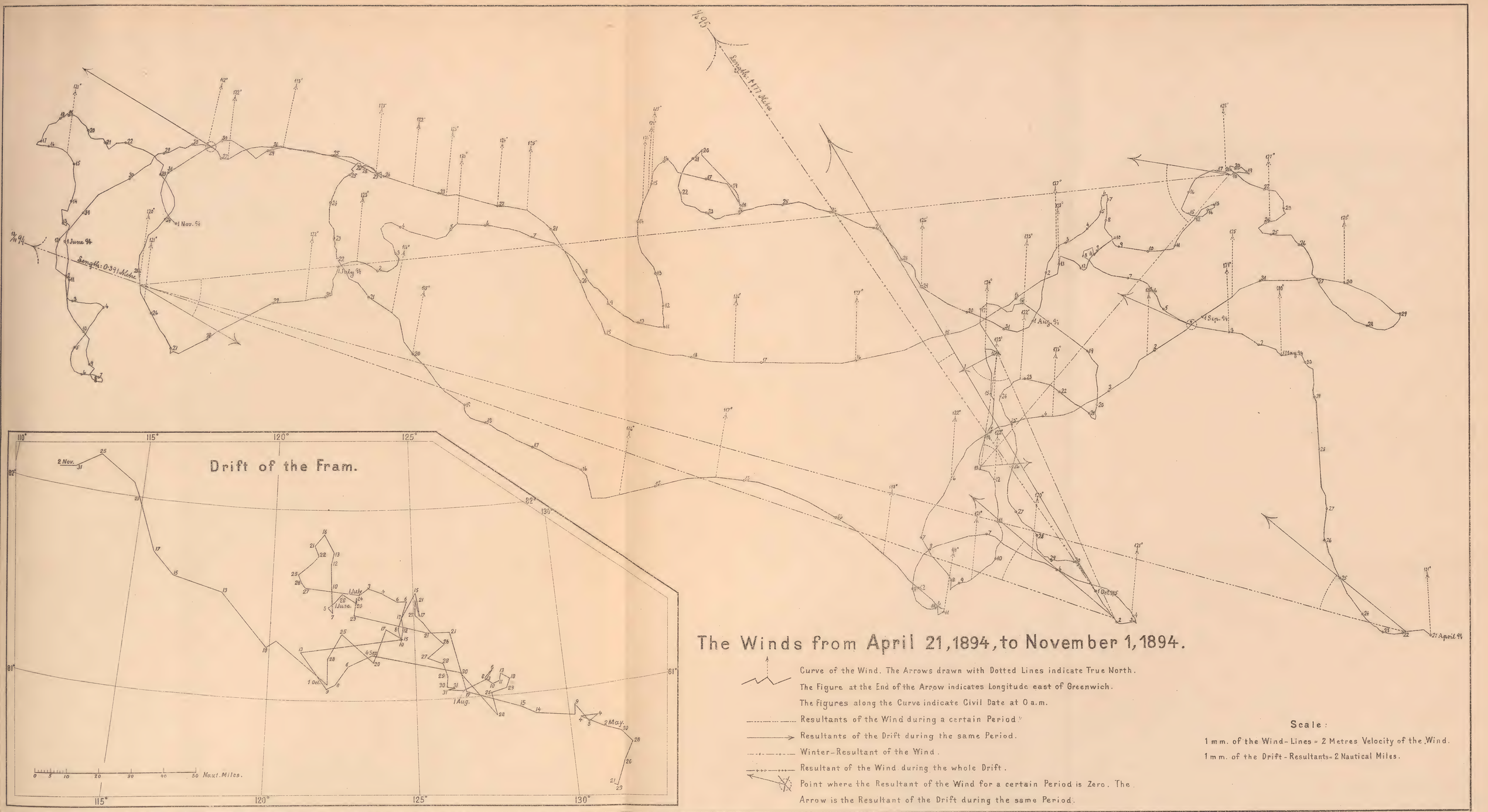
is Zero. The

Scale:

1 m m. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 m m. of the Drift-Resultants = 2 Nautical Miles.

Kart-og Litografering skontoret, Kr.ani.



The Winds from April 21, 1894, to November 1, 1894.

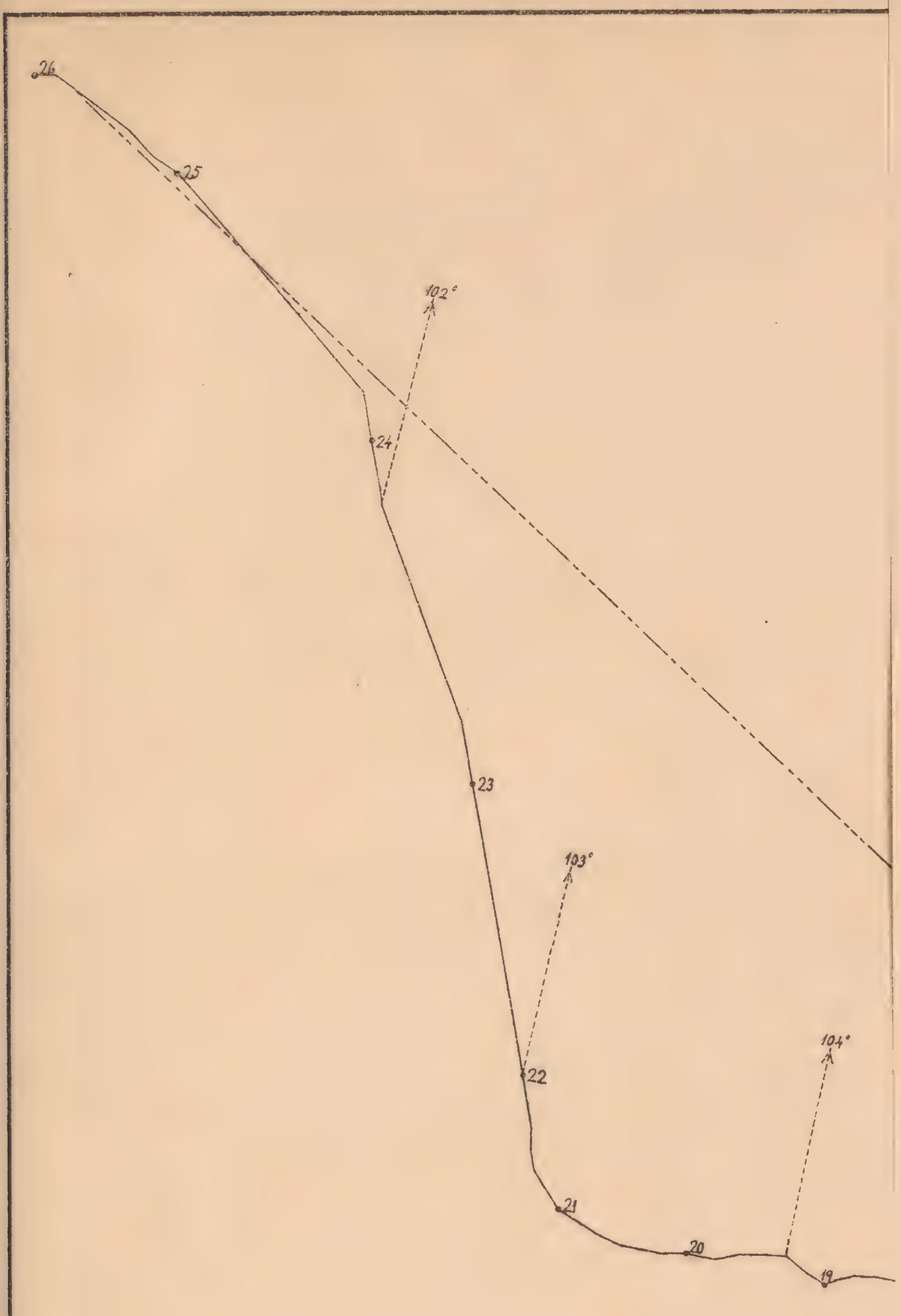
Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.
The Figure at the End of the Arrow indicates Longitude east of Greenwich.
The Figures along the Curve indicate Civil Date at 0 a.m.
Resultants of the Wind during a certain Period.
Resultants of the Drift during the same Period.
Winter-Resultant of the Wind.
Resultant of the Wind during the whole Drift.
Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

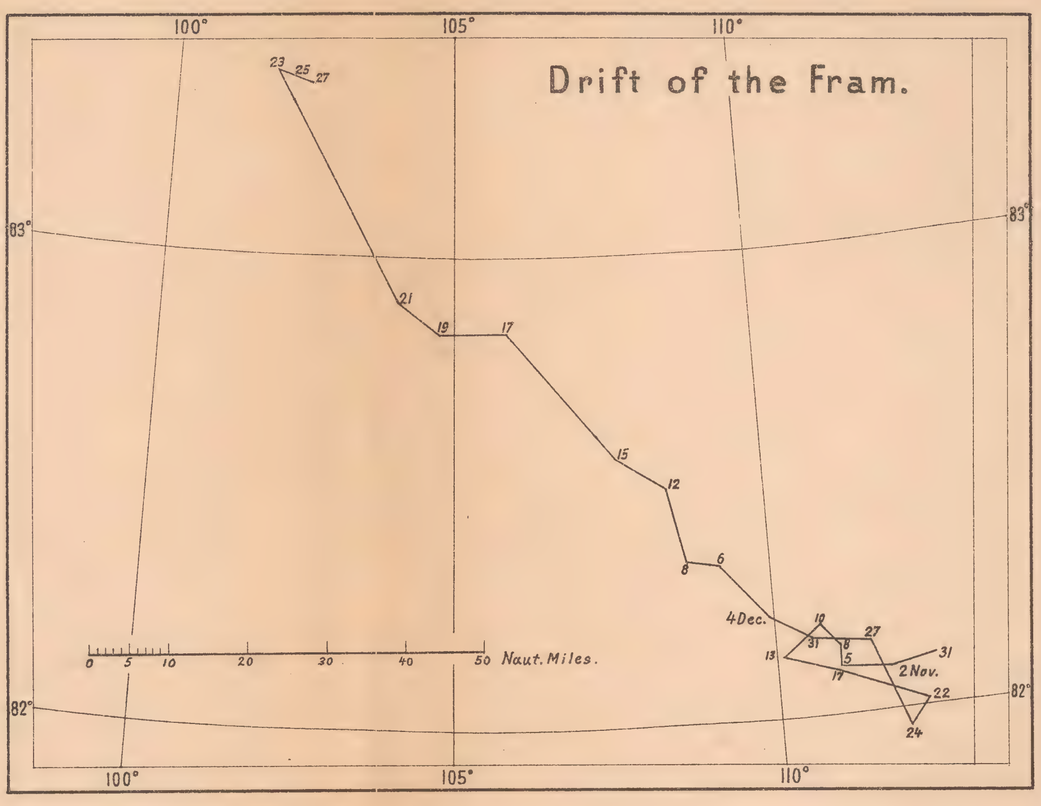
Scale:

1 mm. of the Wind-Lines = 2 Metres Velocity of the Wind.
1 mm. of the Drift-Resultants = 2 Nautical Miles.

Kart- og Litografiforingskontoret, Kristiania.

The Norvegian North Polar Expedition 1893-1896.





The Winds from November 1, 1894 to December 26, 1894.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.

The Figure at the End of the Arrow indicates Longitude east of Greenwich.

The Figures along the Curve indicate Civil Date at 0 a.m.

Resultants of the Wind during a certain Period.

Resultants of the Drift during the same Period.

Winter-Resultant of the Wind.

Resultant of the Wind during the whole Drift.

Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

Scale:

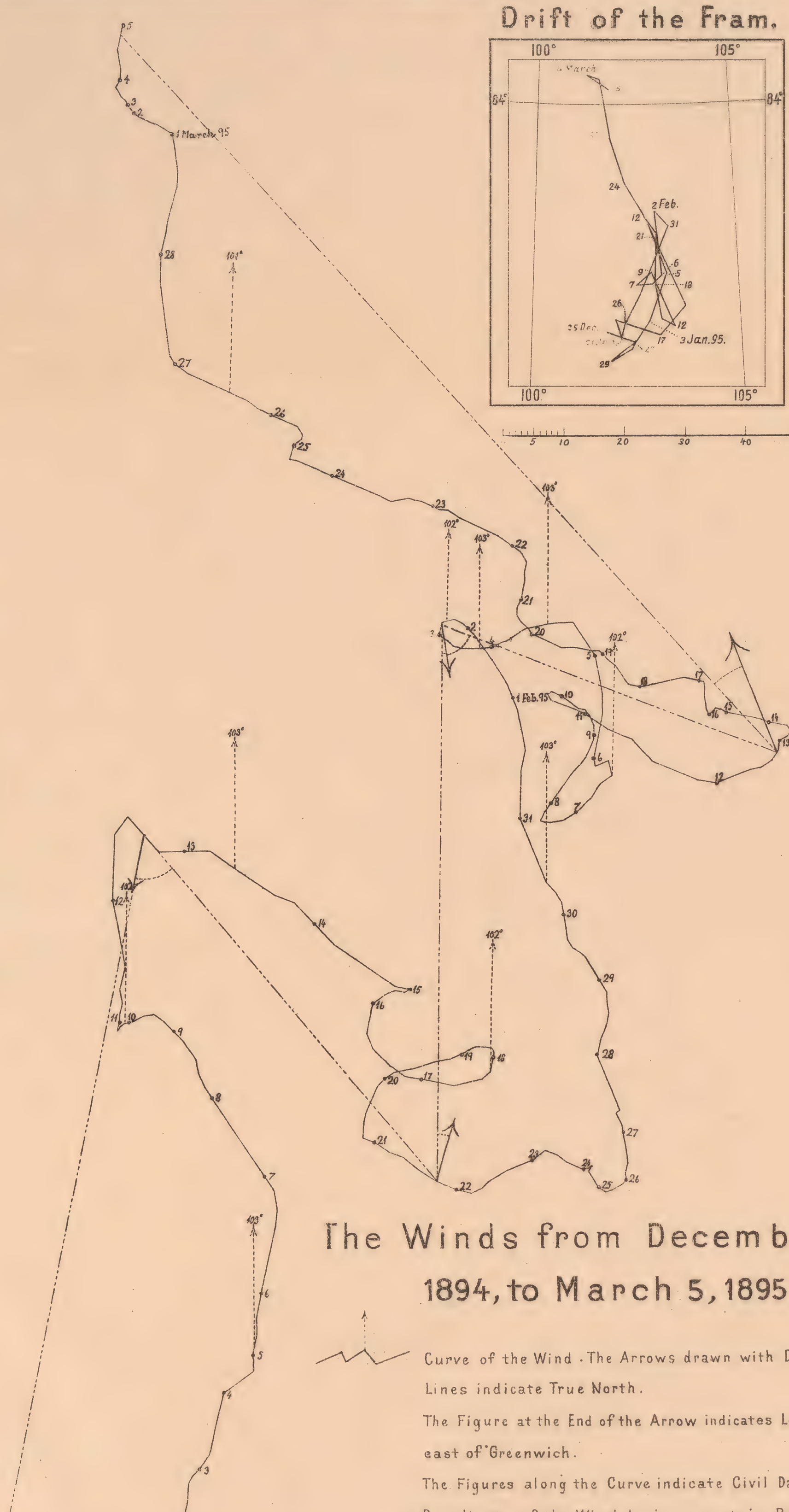
1 m m. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 m m. of the Drift-Resultants = 2 Nautical Miles.

Kart-og Litograferingskontoret, Kristiania

Drift of the Fram.

5 10 20 30 40 50 Naut. Miles.



The Winds from December 25, 1894, to March 5, 1895.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.

The Figure at the End of the Arrow indicates Longitude east of Greenwich.

The Figures along the Curve indicate Civil Date at 0 a.m.

Resultants of the Wind during a certain Period.

Resultants of the Drift during the same Period.

Winter-Resultant of the Wind.

Resultant of the Wind during the whole Drift.

Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period

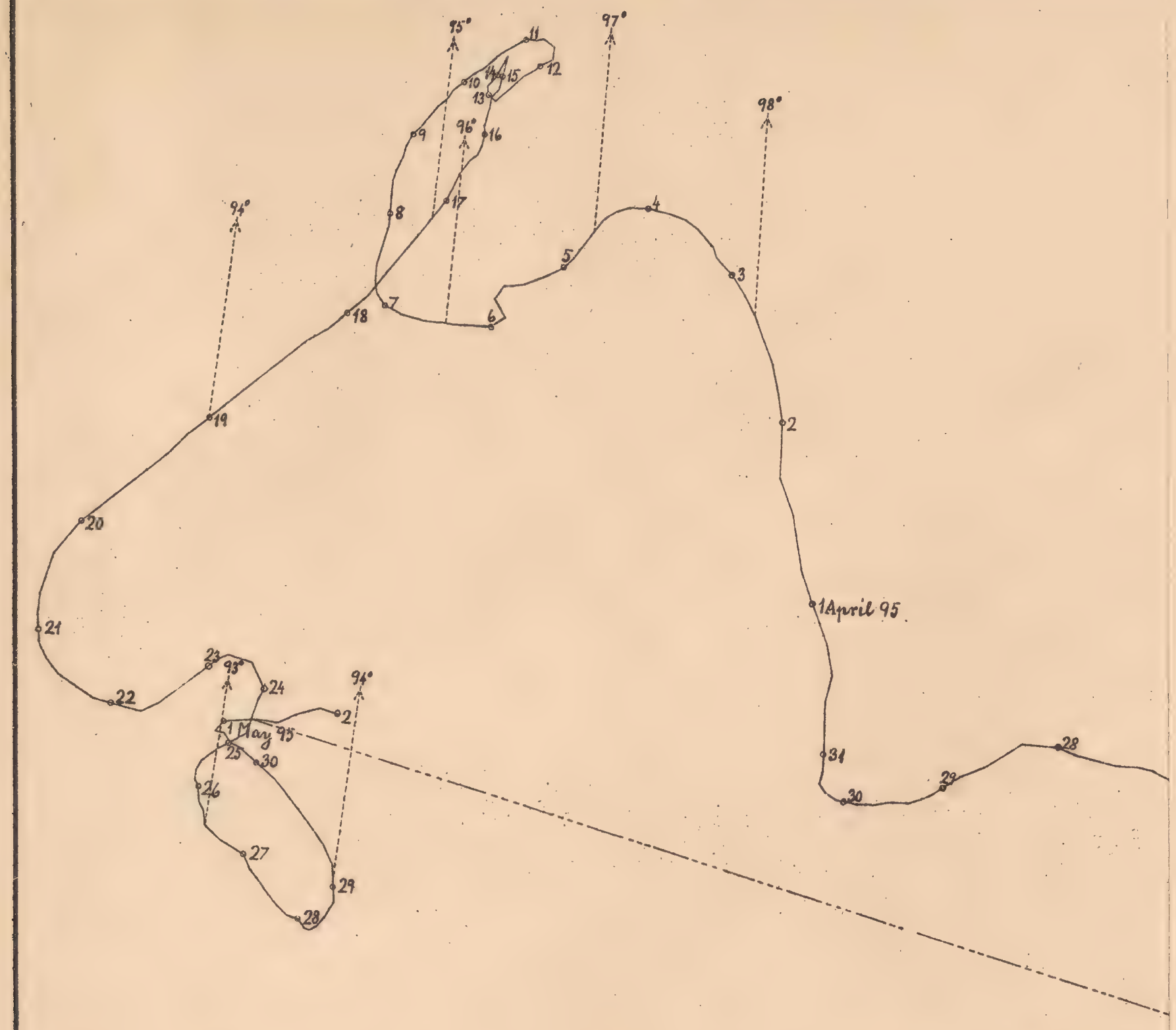
Scale:

1 m m. of the Wind-Lines = 2 Metres Velocity of the Wind

1 m m. of the Drift-Resultants = 2 Nautical Miles.

Kart-og Litograferingskontoret, Kr ania.

The Norvegian North Polar Expedition 1893-1896.



The Winds from March 1, 1895, to May

Curve of the Wind. The Arrows drawn with Dotted Lines indicate T

The Figure at the End of the Arrow indicates Longitude east of Green

The Figures along the Curve indicate Civil Date at 0 a.m.

Resultants of the Wind during a certain Period.

Resultants of the Drift during the same Period.

Winter-Resultant of the Wind.

Resultant of the Wind during the whole Drift.

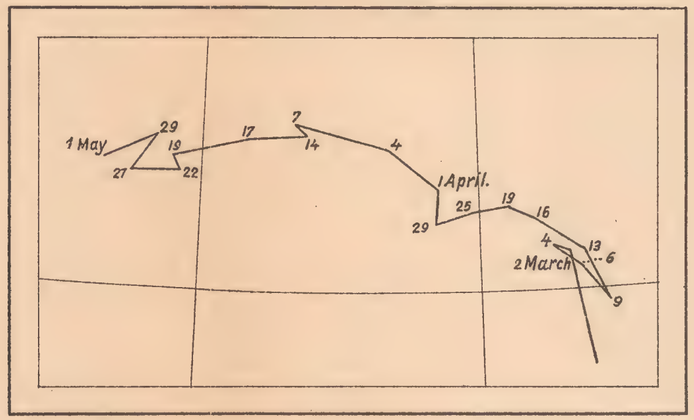
Point where the Resultant of the Wind for a certain Period is Z
Arrow is the Resultant of the Drift during the same Period.

Scale:

1 mm. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 mm. of the Drift-Resultants = 2 Nautical Miles.

Drift of the Fram.



The Winds from March 1, 1895, to May 2, 1895.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.
The Figure at the End of the Arrow indicates Longitude east of Greenwich.
The Figures along the Curve indicate Civil Date at 0 a.m.
Resultants of the Wind during a certain Period.
Resultants of the Drift during the same Period.
Winter-Resultant of the Wind.
Resultant of the Wind during the whole Drift.
Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

Scale:

1 mm. of the Wind-Lines = 2 Metres Velocity of the Wind.
1 mm. of the Drift-Resultants = 2 Nautical Miles.

Kart- og Litografering skontoret, Kristiania.

Th

o October 8, 1895.

d Lines indicate True North.

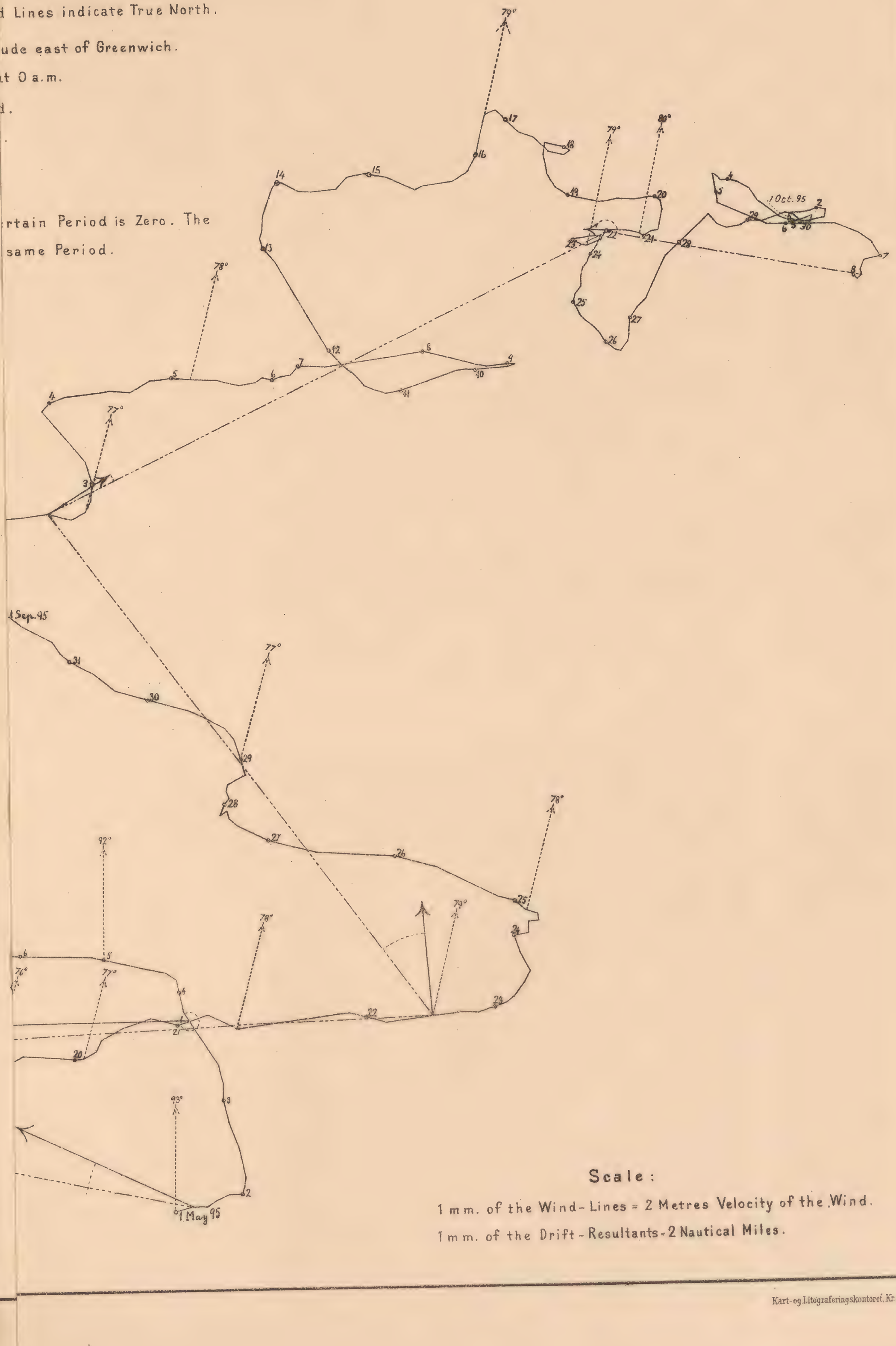
ude east of Greenwich.

t 0 a.m.

d.

rtain Period is Zero. The

same Period.

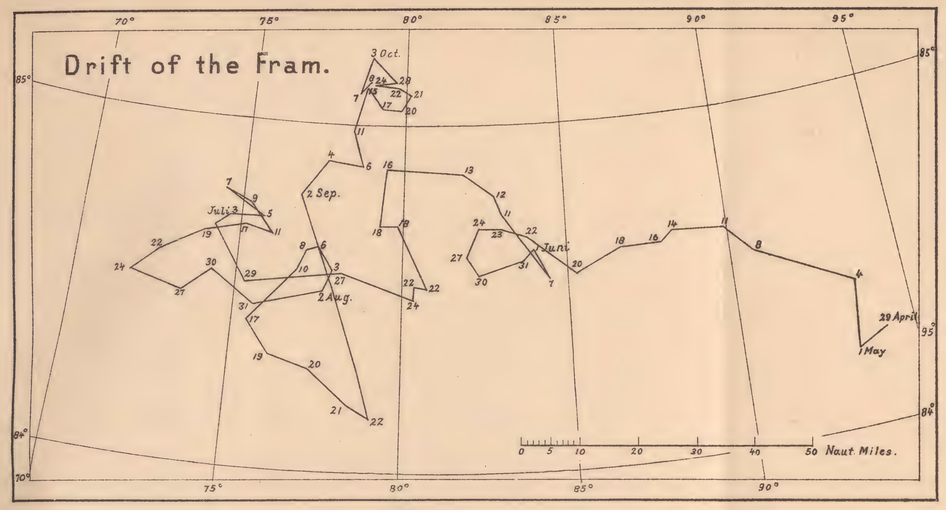


Scale:

1 m m. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 m m. of the Drift-Resultants = 2 Nautical Miles.

Kart- og Litograferingskontoret, Kr.ania.



The Winds from May 1, 1895, to October 8, 1895.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.

The Figure at the End of the Arrow indicates Longitude east of Greenwich.

The Figures along the Curve indicate Civil Date at 0 a.m.

Resultants of the Wind during a certain Period.

Resultants of the Drift during the same Period.

Winter-Resultant of the Wind.

Resultant of the Wind during the whole Drift.

Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

Scale:

1 m m. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 m m. of the Drift-Resultants = 2 Nautical Miles.

Kart-og Litografering skontoret, Kristiania.

Drift of the Fram from October 1, 1895, to January 1, 1896.

Winds drawn with Dotted Lines indicate True North.

The Arrow indicates Longitude east of Greenwich.

The Figures indicate Civil Date at 0 a.m.

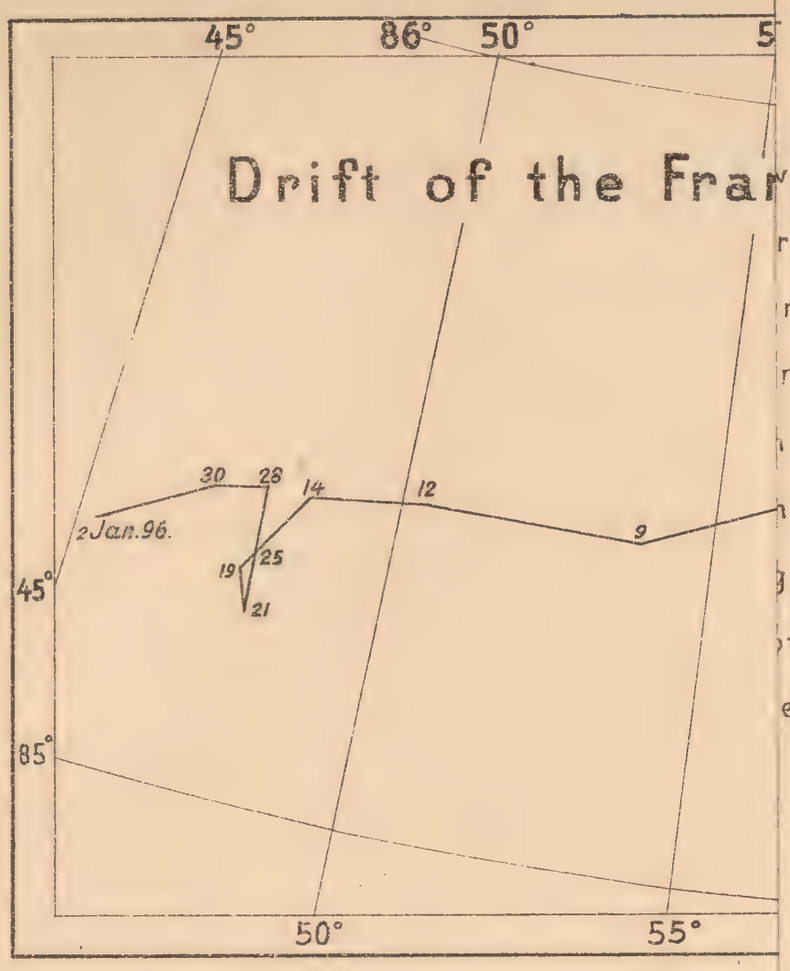
Mean Direction during a certain Period.

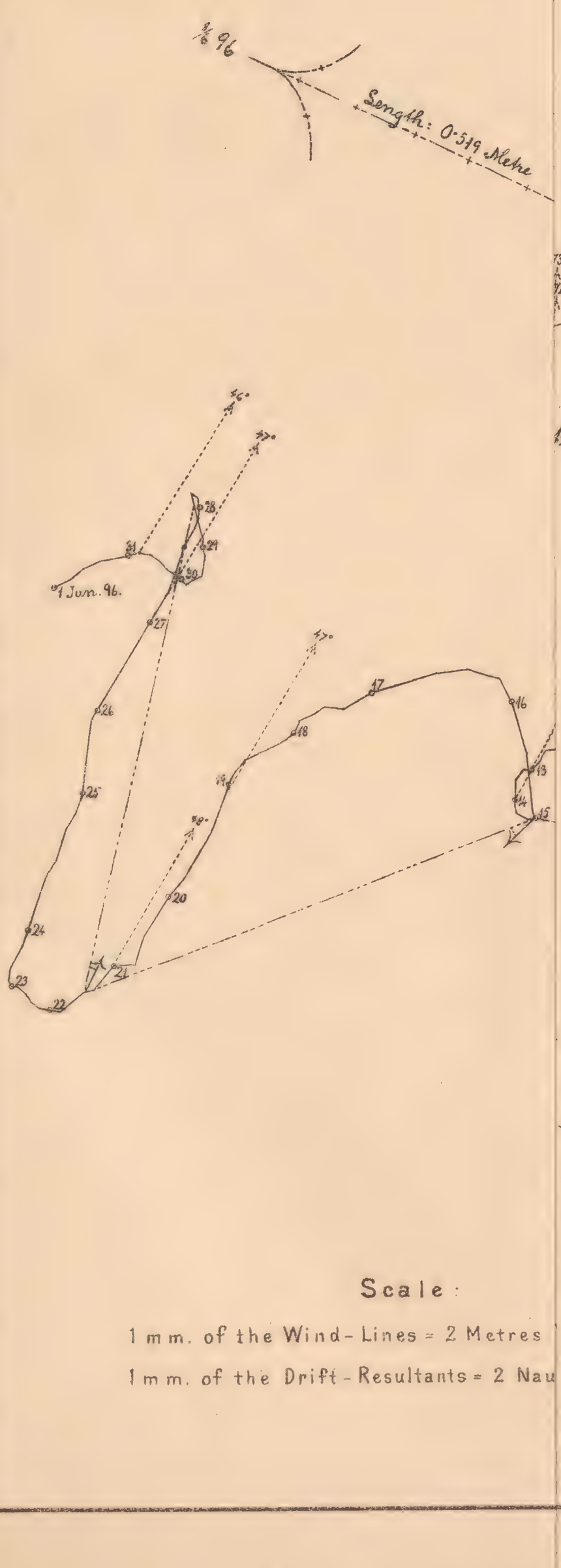
Mean Velocity during the same Period.

Wind-Resultant.

Resultant of the whole Drift.

Where the Velocity of the Wind for a certain Period is Zero. The Resultant is the Drift during the same Period.





Scale:

1 m m. of the Wind-Lines = 2 Metres

1 m m. of the Drift-Resultants = 2 Nau

Kart- og Litograferingskontoret, Kristiania

The Winds from October 1, 1895, to January 1, 1896.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.
The Figure at the End of the Arrow indicates Longitude east of Greenwich.
The Figures along the Curve indicate Civil Date at 0 a.m.
Resultants of the Wind during a certain Period.
Resultants of the Drift during the same Period.
Winter-Resultant of the Wind.
Resultant of the Wind during the whole Drift.
Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

Drift of the Fram.

45° 86° 50° 55° 60° 65° 70° 75° 86° 80°

2 Jan. 96. 1 Dec. 1 Nov. 1 Oct. 85° 80°

0 5 10 20 30 40 50 Naut. Miles.

50° 55° 60° 65° 70° 75°

1/6 96

Length: 0·519 Metre

1 Jun. 96.

1 Dec. 95

1 Nov. 95

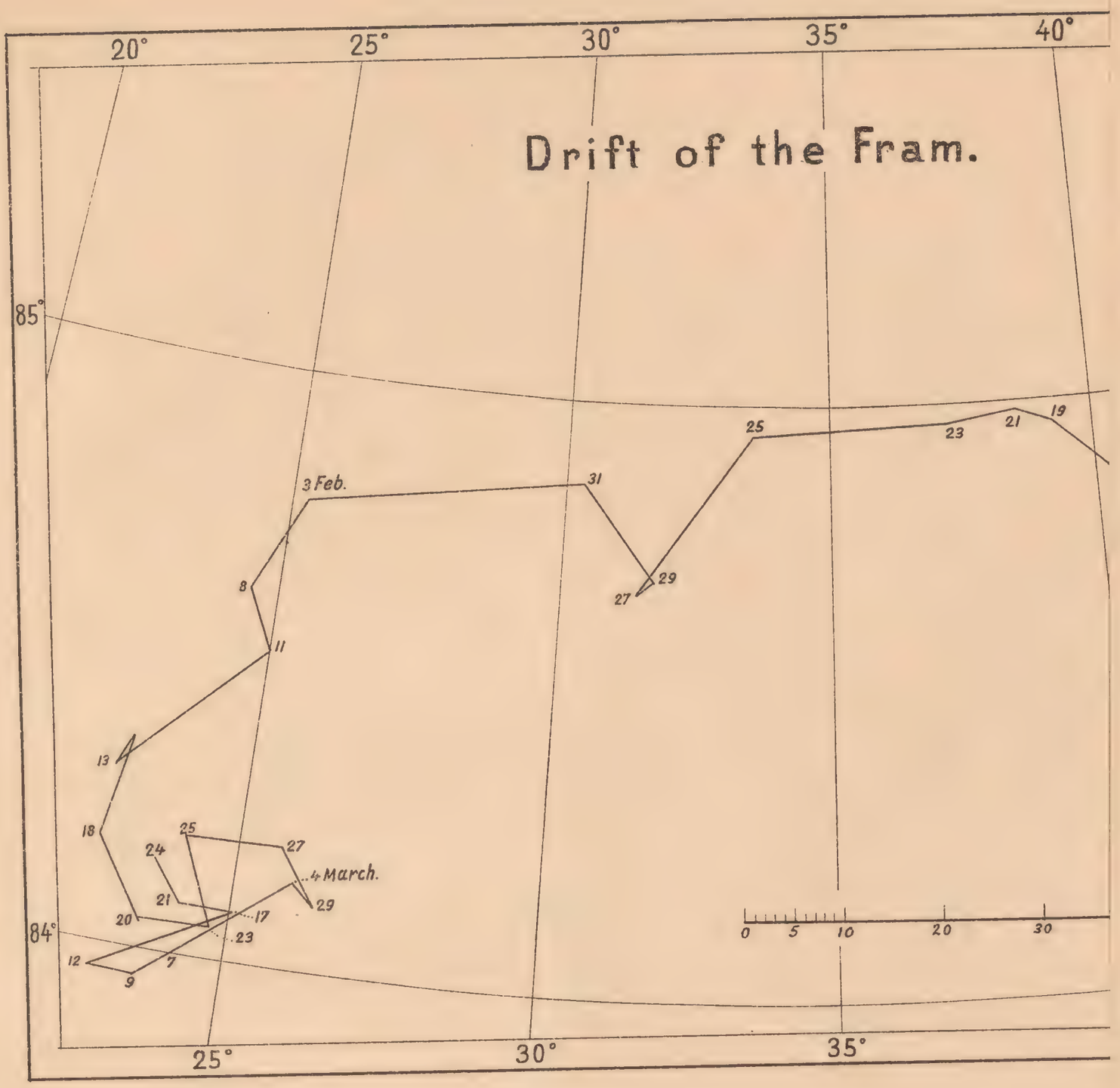
Scale:

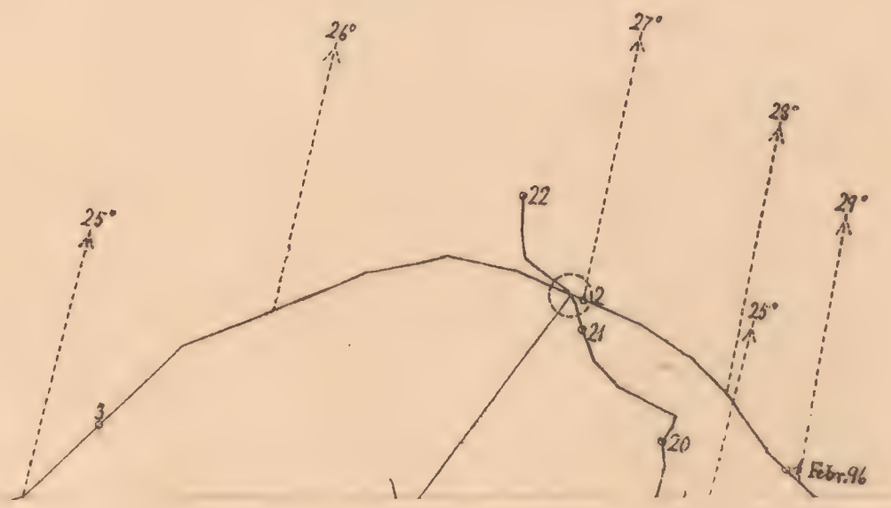
1 mm. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 mm. of the Drift-Resultants = 2 Nautical Miles.

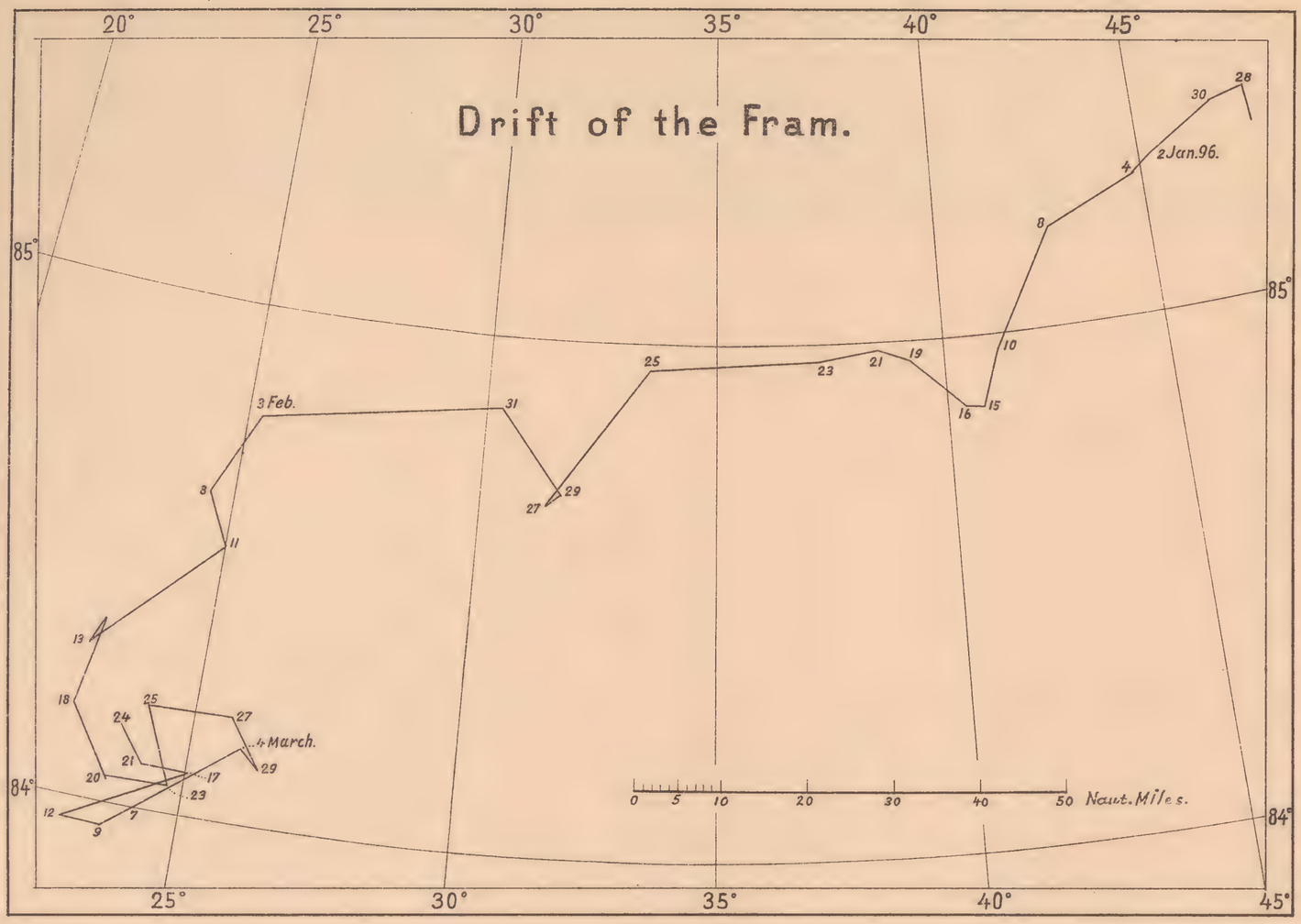
Kart-og Litograferingskontoret, Kristiania.

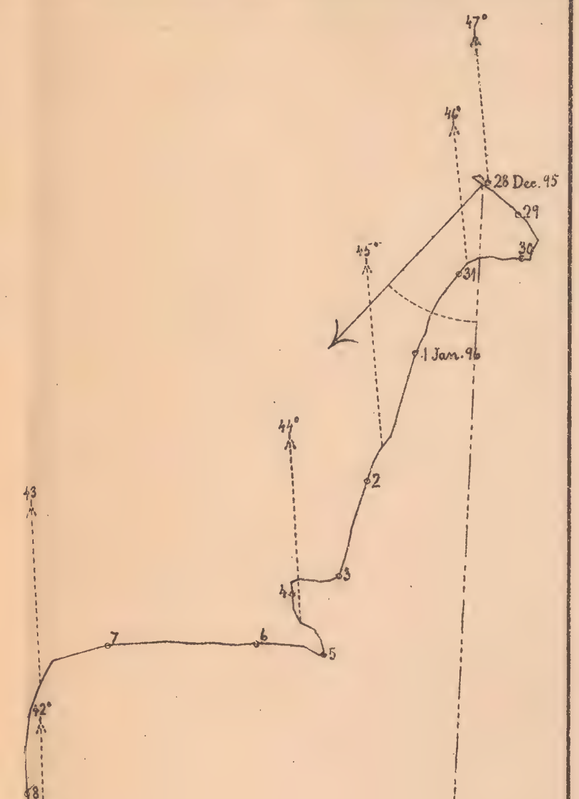
The Norvegian North Polar Expedition 1893-1896.





Drift of the Fram.





The Winds from December 28, 1895. to March 22, 1896.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.

The Figure at the End of the Arrow indicates Longitude east of Greenwich.

The Figures along the Curve indicate Civil Date at 0 a.m.

Resultants of the Wind during a certain Period.

Resultants of the Drift during the same Period.

Winter-Resultant of the Wind.

Resultant of the Wind during the whole Drift.

Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

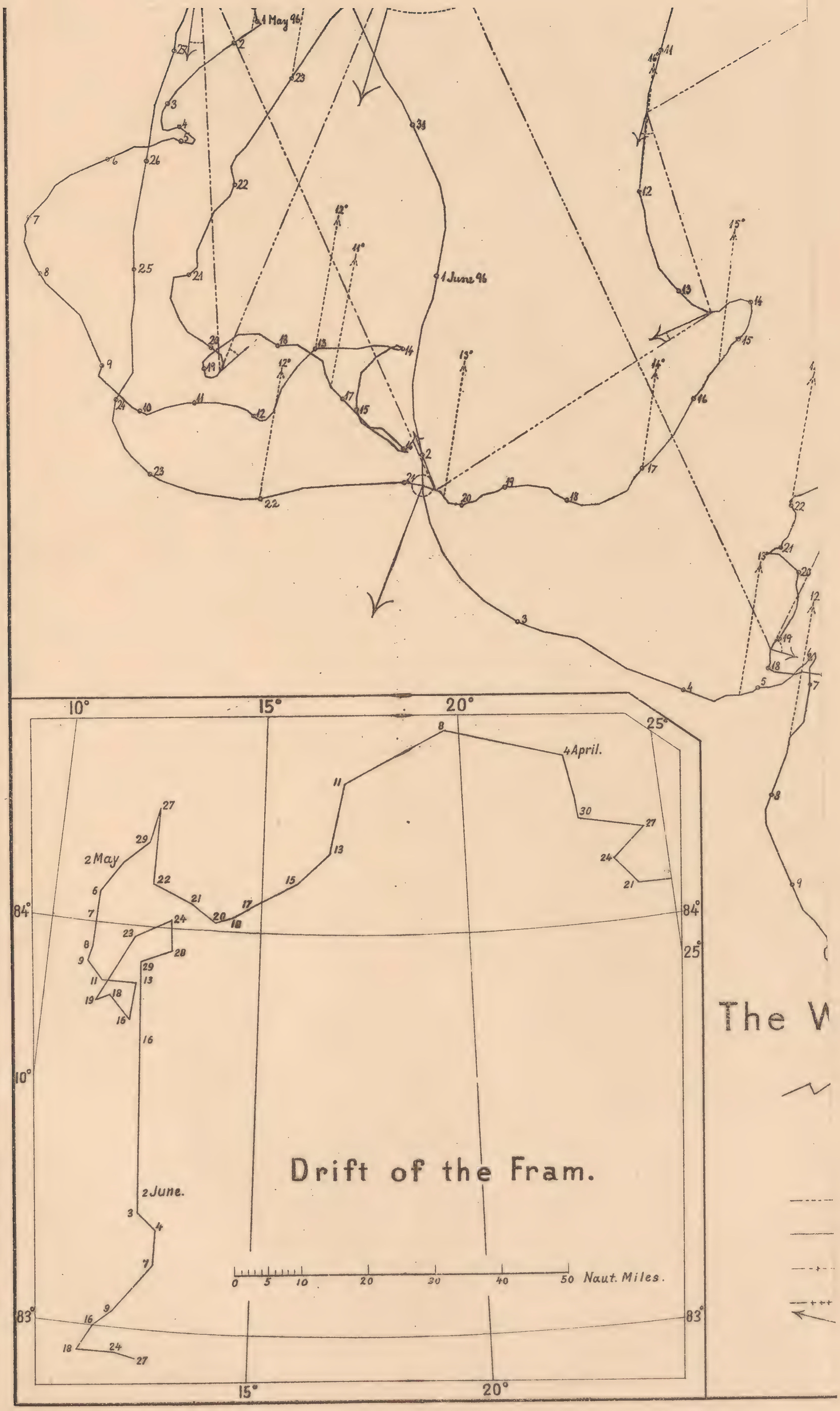
Scale:

1 m m. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 m m. of the Drift-Resultants = 2 Nautical Miles.

Kart-og Litograferingskontoret, Kristiania.

Drift of the Fram.



Scale:

1 m m. of the Wind-Lines = 2 Metres Velocity of the Wind.

1 m m. of the Drift-Resultants = 2 Nautical Miles.

Drift of the Fram.

The Winds from March 18, 1896, to June 28, 1896.

Curve of the Wind. The Arrows drawn with Dotted Lines indicate True North.

The Figure at the End of the Arrow indicates Longitude east of Greenwich.

The Figures along the Curve indicate Civil Date at 0 a.m.

Resultants of the Wind during a certain Period.

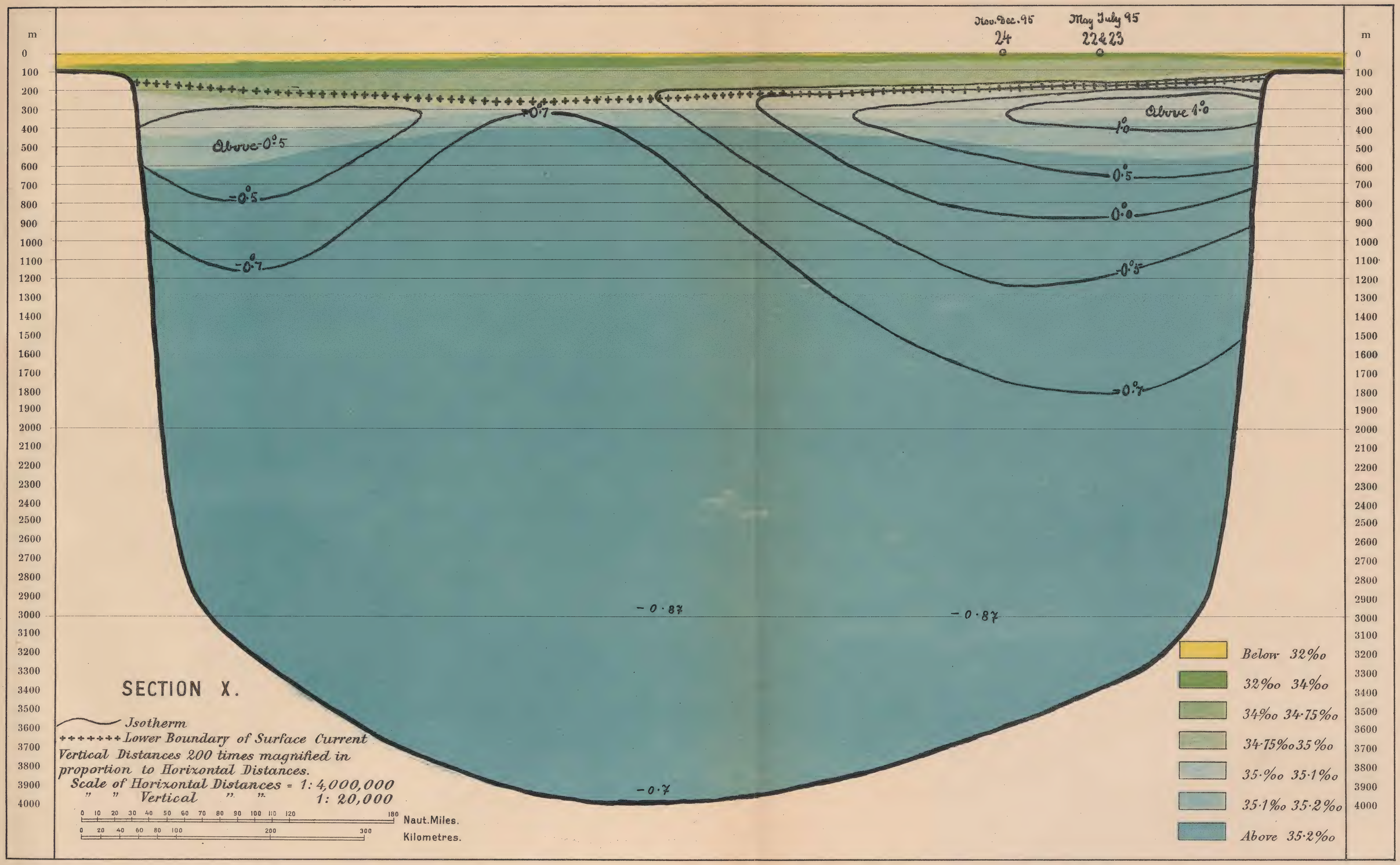
Resultants of the Drift during the same Period.

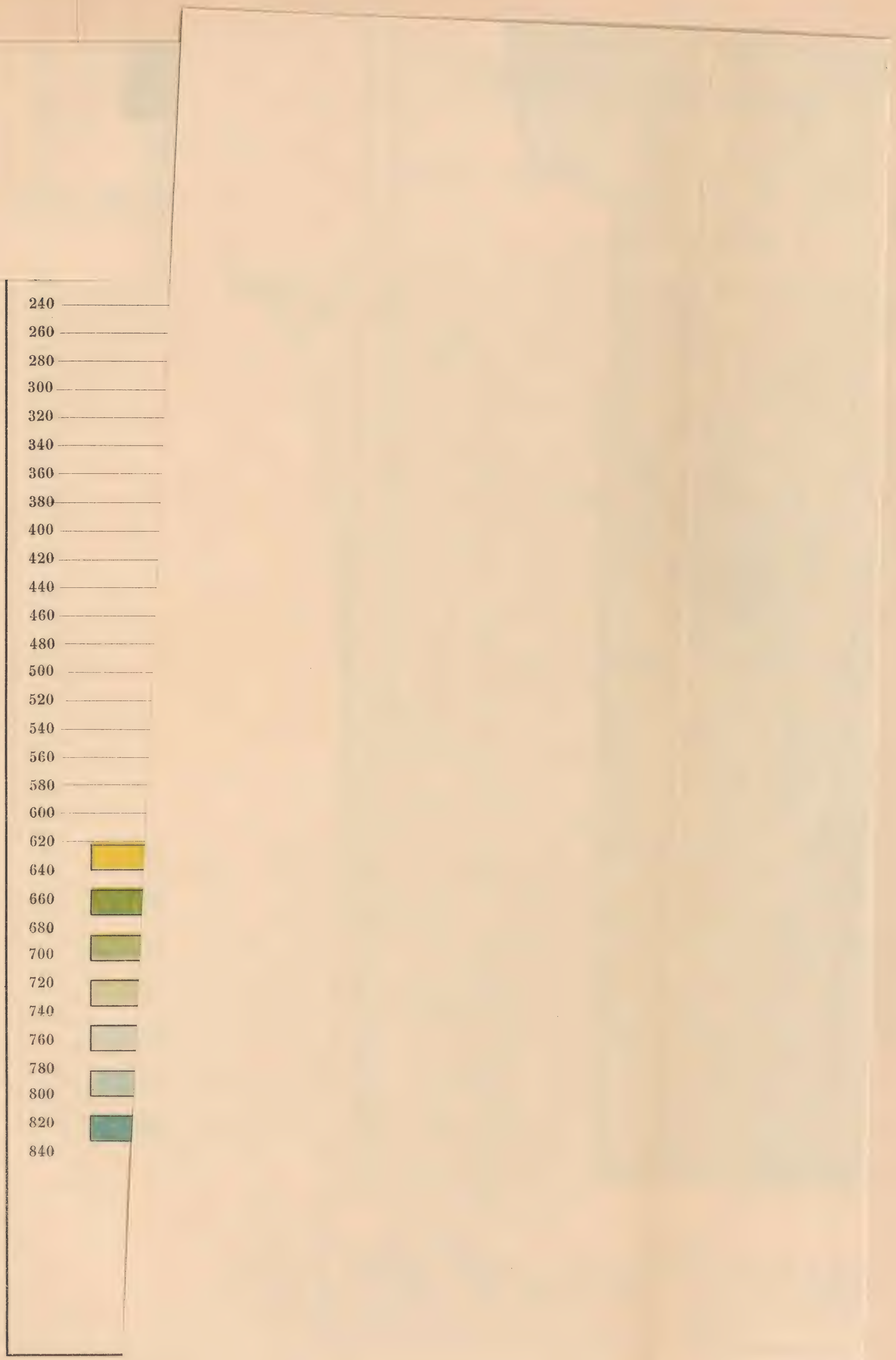
Winter-Resultant of the Wind.

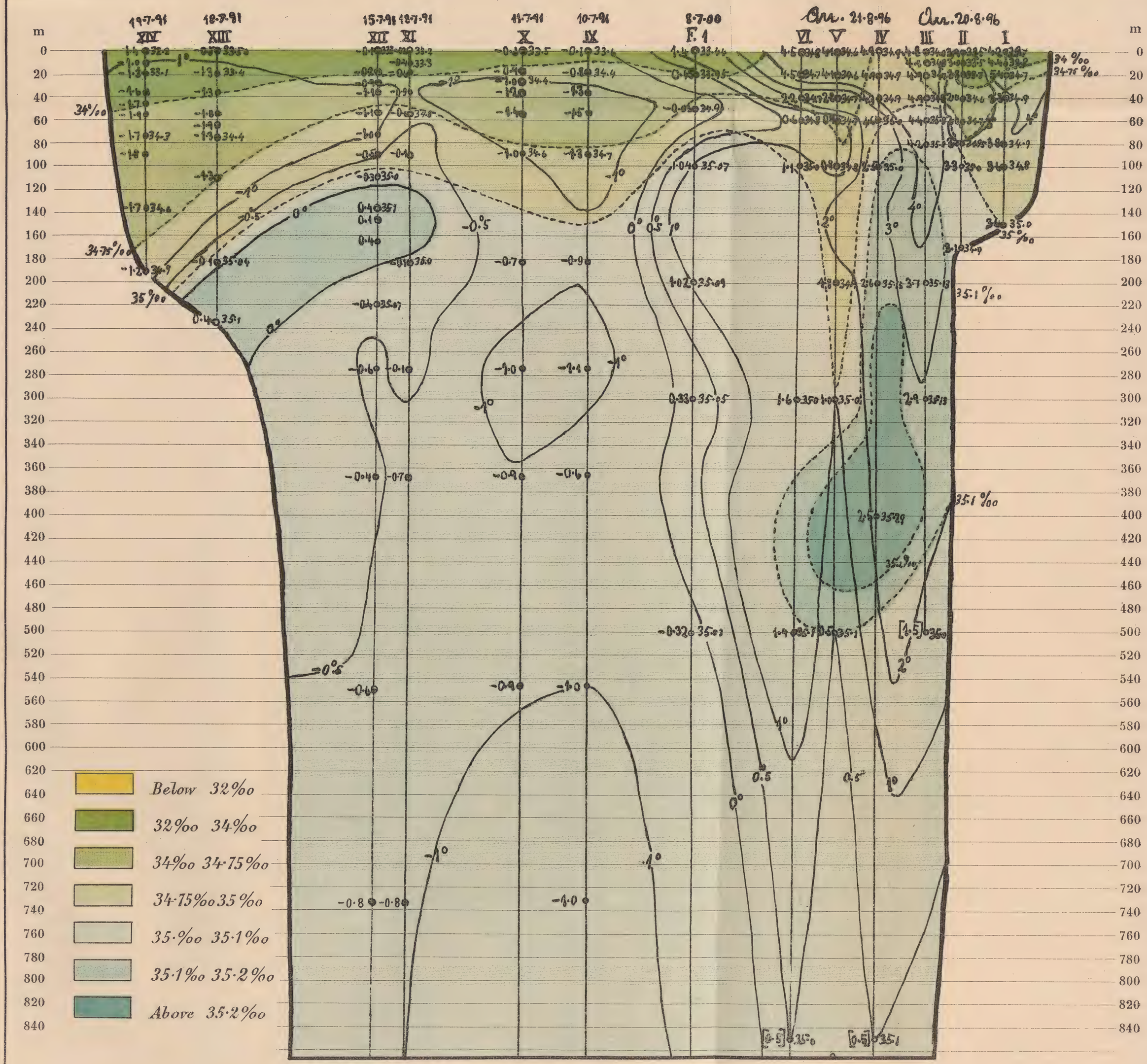
Resultant of the Wind during the whole Drift.

Point where the Resultant of the Wind for a certain Period is Zero. The Arrow is the Resultant of the Drift during the same Period.

Kart- og Litografiingskontoret, Kristiania.


Nov. Dec. 95
24
May July 95
22 & 23
Above -0°5
-0°5
-0°7
0°7
Above 1°0
1°0
0°5
0°0
-0°5
-0°7
-0·87
-0·87
-0·7
SECTION X.
Isotherm
+++++++ Lower Boundary of Surface Current
Vertical Distances 200 times magnified in proportion to Horizontal Distances.
Scale of Horizontal Distances = 1: 4,000,000
" " Vertical " " 1: 20,000
Naut. Miles.
Kilometres.
Below 32‰
32‰ 34‰
34‰ 34·75‰
34·75‰ 35‰
35·‰ 35·1‰
35·1‰ 35·2‰
Above 35·2‰


240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
740
760
780
800
820
840



SECTION XI.

Isotherm. Isohaline.

Vertical Distances 1000 times magnified in proportion to Horizontal Distances.

Scale of Horizontal Distances = 1: 4,000,000

" " Vertical " " 1: 4,000

0 10 20 30 40 50 60 70 80 90 100 110 120 180 Naut. Miles.

0 20 40 60 80 100 200 300 Kilometres.

THE NO

m

0

100

200

300

400

500

600

700

800

900

1000

1100

1200

1300

1400

1500

1600

1700

1800

1900

2000

2100

2200

2300

2400

2500

2600

2700

2800

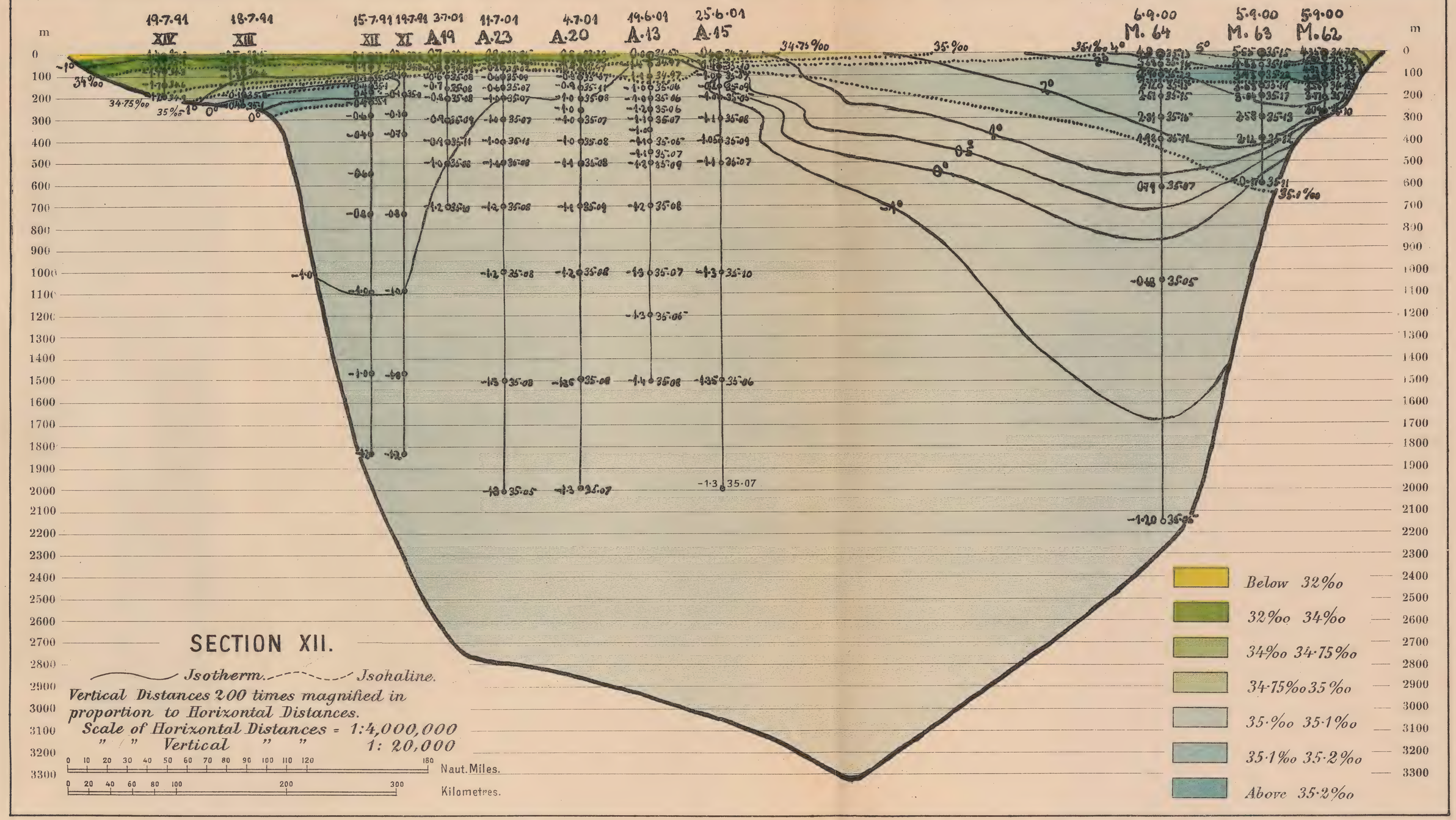
2900

3000

3100

3200

3300



SECTION XII.

Isotherm. *Isohaline.*

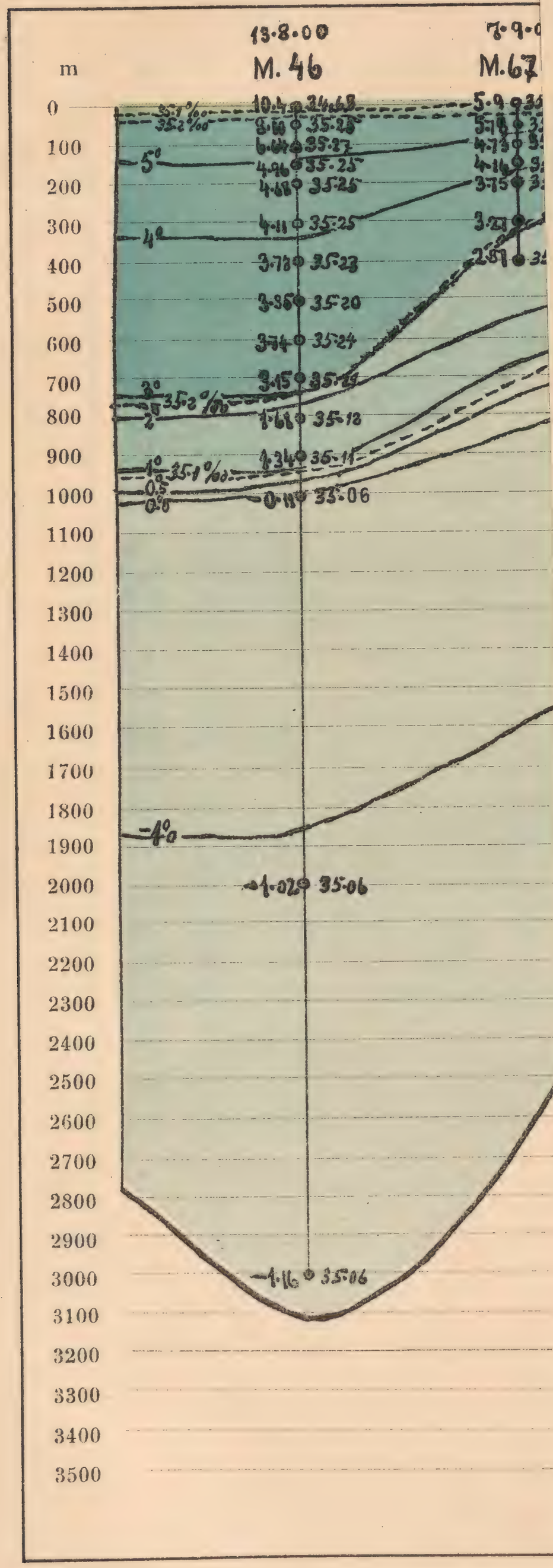
Vertical Distances 200 times magnified in proportion to Horizontal Distances.

Scale of Horizontal Distances = 1:4,000,000

" " Vertical " " 1: 20,000

0 10 20 30 40 50 60 70 80 90 100 110 120 180 Naut. Miles.

0 20 40 60 80 100 200 300 Kilometres.


13·8·00
M. 46
7·9·0
M. 67
m
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
35·1‰
35·2‰
5°
4°
3°
2°
1°
0·5°
0°
-4°
10·4 24·68
5·9
3·78 35·23
3·74 35·24
3·15 35·29
1·61 35·18
1·34 35·11
0·11 35·06
-1·02 35·06
-1·16 35·06

13·8·00 M. 46 | 7·9·00 M.67 | 6·9·00 M.65 | 5·9·00 M.63 | 21·8·96 Chr. IV | North Polar Basin

m

Spitsbergen Ridge

Transverse Ridge

SECTION XIII.

Isotherm. *Isohaline.*

Vertical Distances 400 times magnified in proportion to Horizontal Distances.

Scale of Horizontal Distances = 1: 8,000,000

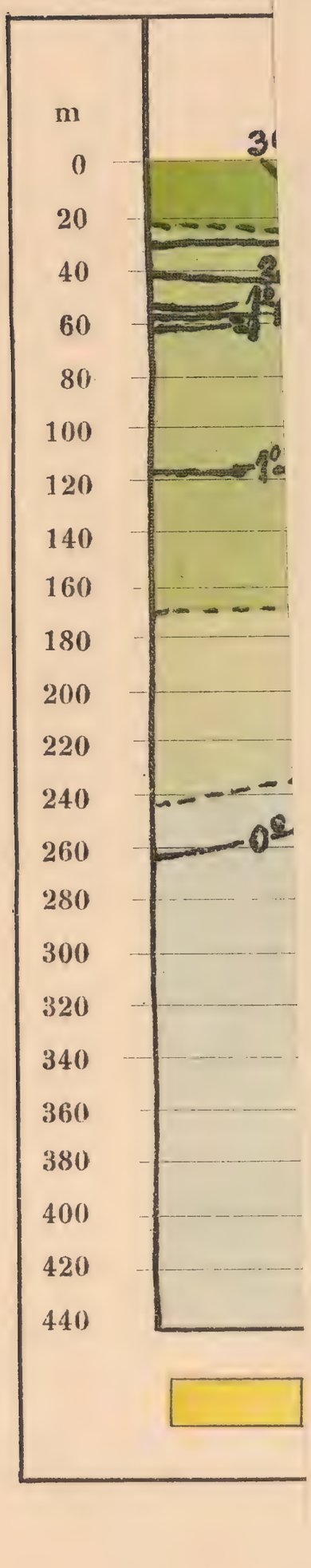
" " Vertical " " 1: 20,000

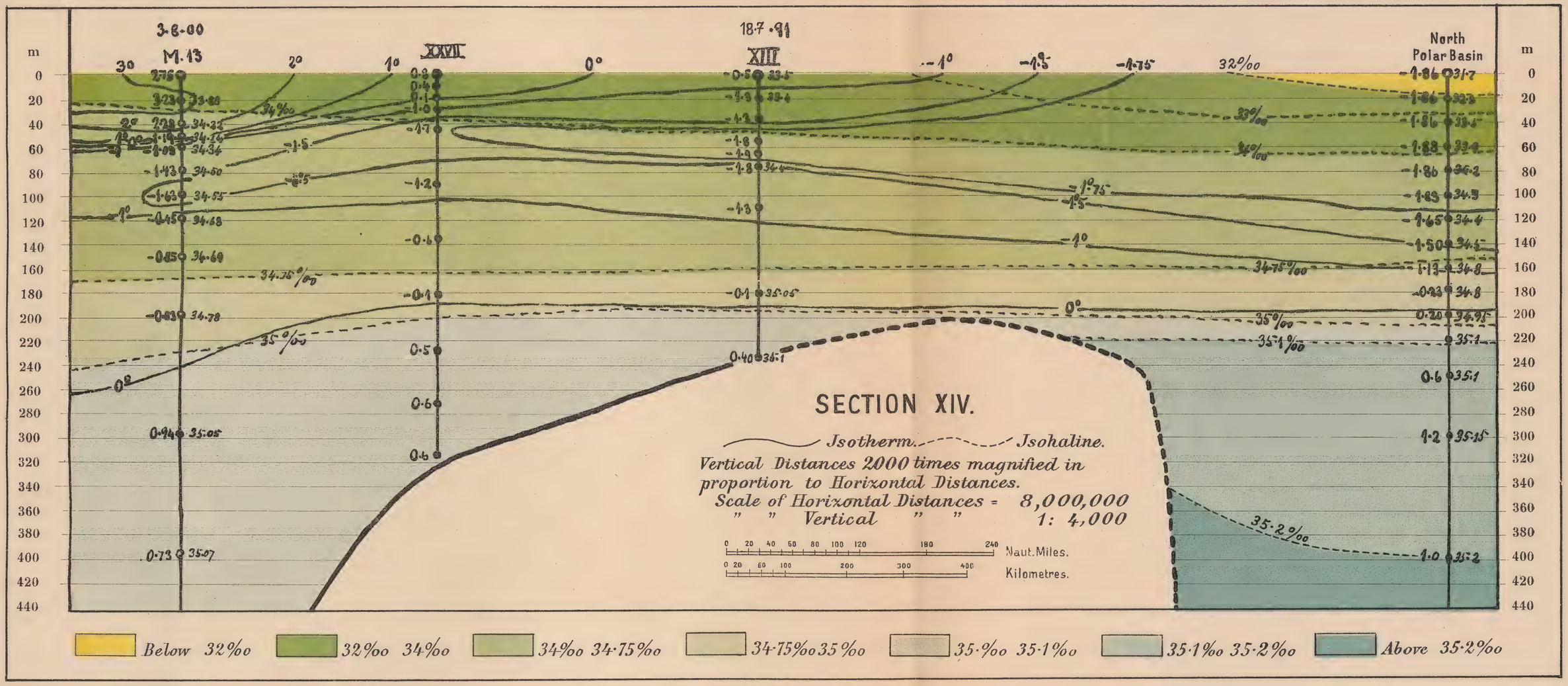
0 20 40 60 80 100 120 180 240 Naut. Miles.

0 20 60 100 200 300 400 Kilometres.

Below 32‰	
32‰ 34‰	*35·‰ 35·1‰*
34‰ 34·75‰	*35·1‰ 35·2‰*
34·75‰ 35‰	*Above 35·2‰*

THE NORWEG


m
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440


SECTION XIV.
Jsotherm. Jsohaline.
Vertical Distances 2000 times magnified in proportion to Horizontal Distances.
Scale of Horizontal Distances = 8,000,000
" " Vertical " " 1: 4,000
Naut. Miles.
Kilometres.
North Polar Basin
M.13
XXVII
XIII
Below 32‰
32‰ 34‰
34‰ 34·75‰
34·75‰ 35‰
35·‰ 35·1‰
35·1‰ 35·2‰
Above 35·2‰

X.

ON HYDROMETERS AND THE SURFACE TENSION OF LIQUIDS

BY

FRIDTJOF NANSEN.

I.

ERRORS OF THE HYDROMETER.

Most investigators who have used the hydrometer for determining the specific gravity of sea-water have experienced certain variations or irregularities in its indications, which were beyond their control, and which they could not explain. This has led several eminent oceanographers to condemn the hydrometer as not suitable for accurate oceanographic work. The reason why the hydrometer has gained such a bad reputation, and, as I believe, in most cases justly, is that the real origin and nature of its chief errors or irregularities have not been known.

The irregular errors have generally been ascribed to one of the following causes, 1) inaccuracy in the determination of the temperature of the water-sample or of the instrument; 2) electricity; 3) irregularities in the wetting of the stem of the hydrometer; 4) irregular currents in the water; 5) dust, fibres from the towel, or other substances floating on the surface of the water, and influencing the shape of the meniscus round the stem; 6) irregular changes in the surface-tension of the water.

After having gone carefully into the matter, I have come to the conclusion, that the apparent irregularities in the indications of hydrometers no doubt arise chiefly from the last-mentioned cause, — this I hope the following chapters will prove. I hope I shall also be able to demonstrate that if we thoroughly know the nature of the apparent irregular changes in the surface-tension of liquids — in which I think I have succeeded — we are able to make the ordinary hydrometer a very useful and fairly trustworthy instrument for oceanographic research, while for very accurate determinations, hydrometers of special construction have to be used.

On the other hand, I believe my investigations will prove that if we do not fully know the changes in the surface-tension, and consequently do not know how to prevent them, or how to secure a uniform surface-tension, the determinations by the hydrometer of the ordinary type are liable to very serious errors, which may, under ordinary circumstances, amount to 0·0002 or 0·0003 of the specific gravity.

As, on the whole, most oceanographers have hitherto paid little attention to the changes in the surface-tension of the water, when using the hydrometer, and as hardly any practical directions have been given how to secure a uniform surface-tension of the water-samples examined, it is to be expected that serious errors may occur in almost any series of determinations made by this instrument.

a) *The influence of differences in the temperature of the water-strata in which the hydrometer floats.*

This influence has been considered by some investigators to be a very important cause of hydrometer errors. Even an eminent oceanographer like Prof. Otto Pettersson, who has strong objections to the use of hydrometers, says: "Hydrometers can be made as sensitive as can be desired. But in proportion as the sensibility increases, the inevitable and uncontrollable errors also increase. How, for example, can the experimenter ensure uniformity of temperature in all parts of the instrument, and at all depths of the water-column wherein it swims?"[1].

I think Pettersson is mistaken in two points here. Firstly, if the sensibility of the hydrometer be increased, especially by diminishing the diameter of its stem as compared with that of the body, the chief source of error is substantially decreased, for the errors caused by changes in the surface-tension of the water are in direct ratio to the diameter of the stem, provided that the volume of the hydrometer is the same. Secondly, want of uniformity of temperature in all parts of the instrument and the water is hardly ever the chief source of error in hydrometer determinations. On the contrary, the errors caused in this manner are as a rule quite insignificant, when the determinations are made with ordinary care. It is in fact a comparatively

[1] 'Scottish Geogr. Mag.' 1894, p. 299, footnote.

easy matter to attain so much uniformity of temperature that the errors, which might be caused in this manner, cannot exceed, say a unit in the fifth place of decimals, which would be equal to an error in the salinity of about 0·01 ‰.

If the water-samples and the hydrometer have very nearly the temperature of the room, it is not difficult to keep the temperature so uniform that there will never be a difference of more than perhaps a few tenths of a degree between the temperature near the water-surface, and that near the bottom of the glass cylinder, a fact which is easily ascertained by measuring the temperature at the various depths. If a somewhat rapid change of temperature be unavoidable during the observations, tolerable uniformity can be attained by moving the hydrometer rapidly up and down, thus stirring the water before each reading, and at the same time helping the instrument to assume the temperature of the water. If, moreover, the temperature for each hydrometer-reading be measured at the depth below the water-surface at which the middle of the glass body of the hydrometer is found, when floating freely, the temperature obtained will certainly not differ as much as 0·1° C. from the mean temperature of the water in which the hydrometer-body is floating, the small differences which may occur in the water-strata surrounding the stem of the hydrometer naturally having very little influence. If a good thermometer, divided into 0·1° C., be used, this error of temperature can easily be reduced to 0·05° C.

If the observations with the hydrometer be made in water with a temperature of about 17·5° C., an error in the temperature of ± 0·05° C. will correspond to an error in the hydrometer-reading of ± 0·00001, provided that the sea-water has a salinity of about 35 ‰; but, as Otto Pettersson himself has pointed out on a previous occasion[1], if the determinations be made at lower temperatures, the errors caused in this manner will be considerably decreased. At temperatures near zero centigrade, an error in the temperature of the water and instrument of as much as ± 0·3° C. or even

[1] Otto Pettersson, 'Contributions to the Hydrography of the Siberian Sea'. 'Vega-Expeditionens vetenskapliga Iakttagelser', vol. II. (1883), p. 329. Here Pettersson says: "At temperatures not exceeding a few degrees on either side of 0° C. we may totally dispense with every correction depending on the temperature, and still obtain numbers representing the specific gravity of the water with correctness in the fourth decimal place."

$\pm$ 0·4° C. would be necessary in order to produce an error of $\pm$ 0·00001 in the determination of the specific gravity[1].

As most observations with the hydrometer during our expedition were made at comparatively low temperatures, between 6° C. and 12° C., and as the temperatures were measured with much care, the possible errors caused in this manner cannot be appreciable, and may be left entirely out of consideration.

If, for very delicate determinations, the uniformity of temperature attained by the method mentioned above is not sufficiently satisfactory, or if the temperatures of the room or the water-sample are changing too rapidly, a greater degree of uniformity in the temperature of the water can easily be attained by placing the glass cylinder containing the water-sample in a wider glass cylinder with water which is made as nearly as possible of the same temperature as the water-sample. I have found this method very convenient, especially when I wished to make observations at temperatures differing from that of the room; and it has proved to be easy, in this manner, to keep the temperature of the water-sample fairly constant for some length of time.

Another and still more convenient method is simply to make the observations in a glass cylinder surrounded by a vacuum. I have had a double cylinder of this kind made, and find that it insulates fairly well, and that the changes of temperature in the water-sample take place much more gradually, even when its temperature differs a good deal from that of the room.

b) *The influence of electricity on the indications of the hydrometer.*

Experiments have been made by Admiral Makaroff and Mr. Terechin[2] on this point, but with no conclusive results. Although time has not allowed me to make experiments in this respect, I believe that in very delicate determinations of the specific gravity by the hydrometer, attention would also have to be paid to the electricity, which, for instance, may be developed by wiping the glass hydrometer; but I do not think the electricity is of much importance

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[1] The slight differences which may exist between the temperature of the hydrometer and that of the water, will practically be of little importance, even if they were as much as some tenths of a degree centigrade. A temperature difference of 0·1° C. will only change the volume of a hydrometer of 'Jena Normal-Glass 16^{III}' 0·0000024.

[2] See Makaroff, 'Le Vitiaz et l'Océan Pacifique', St. Petersburg, 1894, p. 58, § 54.

when one considers the greater, well-known irregularities in the determinations by the hydrometer, because these have chiefly a different origin, as we shall see. When correcting the determinations of our expedition, we need not, therefore, pay any attention to possible errors caused by electricity.

c) *The influence of the wetting of the surface of the hydrometer.*

As several investigators have pointed out[1], it is of great importance that the water should thoroughly wet the surface of the hydrometer, and especially of its stem. The reason is clear; for if a perfectly dry hydrometer be slowly immersed in the fluid, and not allowed to sink any deeper than to its apparent equilibrium, the meniscus does not assume its natural development round the stem, as may easily be seen by the aid of a lens. As soon as the stem is wetted for a certain distance above the water-surface, *e. g.* by immersion, the instrument will sink to its natural equilibrium, provided that the surface of the stem is perfectly clean near the water-line.

During the expedition on board the Fram, I did not like to wet the stem for more than a short distance above the water-level, for fear that, if too much water adhered to the stem, it might, even if it did not form drops, influence the weight of the instrument appreciably. I also feared that the brine or salt formed on the stem by the evaporation of this water, might influence the shape or size of the meniscus, and thus make the indications of the instrument less accurate. I now think that this precaution was exaggerated, the essential point being always to keep the surface of the stem thoroughly wetted near the meniscus.

During the expedition, I also had the same experience as Prof. Krümmel[2], namely, that only after having immersed the hydrometer in the sea-water once or twice, taking it out and wiping it dry each time, did I attain fairly identical determinations. This was therefore nearly always done.

The reason of this might be expected to be that the surface of the glass instrument is not quite smooth, and that after some time, when dry, a layer of air is condensed upon it. By wiping, when moist, this layer of

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[1] See Otto Krümmel, 'Ueber einige neuere Beobachtungen an Aräometern'. Ann. der Hydr. u. Marit. Meteorol. November, 1894, separate copy, p. 7. See also Maly, Zeitschrift für Instrumentenkunde, 1892, p. 61.

[2] L. c. p. 7.

air is gradually rubbed away, and replaced by water-molecules, forming a film ("Wasserhaut"). In a letter to me, dated February 27th, 1899, Prof. Krümmel refers to the experience of Kohlrausch and others, namely, that the surface of glass absorbs water by immersion, so that the weight of large glass vessels may in this manner be appreciably altered. A hydrometer which has not been used for some time will, according to Krümmel, as a rule give too high readings (equal to 2 mm. of the stem), and he therefore washes it over well with a wash-bottle, and wipes it carefully dry with a good towel. When this proceeding has been repeated several times, the surface of the instrument is to some extent imbued with water, and then only will it give identical indications. "Diese Wirkung der Benetzung äussert sich also nicht nur am Skalenstengel, der das Wasser abstösst, wenn er zu trocken ist, sondern noch viel mehr am Körper des Aräometers".

I do not consider, however, that the above explanation is fully satisfactory. According to my investigations, the conditions of the surface of the body of the hydrometer have considerably less influence upon its indication than *the condition of the surface of the stem at and near the water-line.* Provided that the latter remains unaltered, it will hardly, for practical purposes, affect the indication of the instrument appreciably, whether the surface of its body is thoroughly wetted or not.

The chief reason why fairly identical observations are obtained in the above-mentioned case, only after having repeatedly immersed the instrument in the water in a glass cylinder, and again wiped it dry each time, is, I believe, an entirely different one. By immersing the dry instrument, and again removing it, parts of the water-surface (or surface-film) are carried away on the surface of the instrument, and a fresh water-surface is formed. The surface-tension of the water thus increases each time, approaching its maximum. The consequence is that the hydrometer sinks deeper each time, until it approaches its minimum of indication. That this explanation is correct will be proved later.

The following experiment may also prove that it is of little importance how the surface of the body of the hydrometer is wetted. This experiment has been repeated hundreds of times, both on board the Fram, and later. I wipe the hydrometer carefully dry all over, immerse it in the water in a glass cylinder, and take several readings. If I now lift it up, wipe only

the stem dry. and then again immerse it while the body is still wet, I get a higher reading than before, provided the temperature has remained the same. The difference between the readings before and after was generally 0·00010 or 0·00012, with the hydrometer of Åderman and the glass cylinder which I used during the expedition[1]. The reason of this difference cannot be that the surface of the body of the instrument has acquired a new coating of air; for it has remained wet. The reason is evidently that the surface of the water adhering to the instrument has been exposed to the air, and has perhaps also been touched by the not absolutely clean towel; and by the immersion, this exposed water-film with reduced surface-tension is given off to the surface of the water in the cylinder, thus reducing the surface-tension of the latter, as will be seen later.

d) *Influence of the manner in which the hydrometer is dried.*

That the manner in which the hydrometer is dried before its immersion influences the indication, has already been stated by several observers, and it has especially been pointed out that the towels used should be perfectly clean. Some authors have also recommended the wiping of the instrument with a damp towel immediately before its immersion, in order to secure the perfect wetting of the surface of the glass, otherwise the hydrometer would have a tendency to give too high indications[2]. This does not accord with my experience. By using a towel which was not perfectly dry, I noticed that I generally obtained higher determinations of the specific gravity by the hydrometer, than I obtained when a dry towel was used. To my astonishment, I also discovered that if I wiped the stem of the instrument only, but without making it perfectly dry, I then got higher determinations than when I rubbed the stem until it was absolutely dry. Moreover, I discovered that if a perfectly clean towel had been used for some time, so that it had often been saturated with sea-water, the hydrometer would then give higher indications than otherwise, although the towel might apparently be dry when used. The differences between the indications of the hydrometer obtained when the instrument had been carefully wiped with a new,

[1] See Memoir No. IX.
[2] See Maly, l. c. p. 61, and also Krümmel, l. c. p. 7.

dry towel, and those obtained after imperfect wiping or after a damp or much used towel (i. e. one charged with salt) had been employed, would often be as much as 0·00010 or more.

Thinking that the cause of these differences might be that the towels did not make the surface of the glass perfectly clean, but left small fibres etc., on it, I tried a piece of wash-leather for wiping, but this had nearly the same effect as a damp towel, making the indications of the hydrometer between 0.00010 and 0.00013 higher than when a dry towel had been used.

This seemed at first to be in every respect contrary to what might be expected. The results of my investigations, recorded later, afforded, however, an easy explanation. If the hydrometer is not wiped perfectly dry, it will be coated by a film of water which has a very low surface-tension, having been exposed to the air, and having also been much in contact with the towel or wash-leather; for these might leave slight traces of oily substances, even if they were to all appearance perfectly clean, especially if they are directly touched by the hands. When such a hydrometer is immersed, this water-film will immediately spread over the top of the water in the cylinder[1], and will reduce its surface-tension, which, in its turn, will increase the indication of the hydrometer.

By wiping with wash-leather or a towel with salt in it, one cannot easily obtain a perfectly dry surface of the glass, because both leather and towel are to some extent hygroscopic, and have a tendency to give the instrument a thin coating of impure water with a very low surface-tension.

This circumstance is of some importance for our observations taken on board the Fram, as wash-leather was there much used for wiping the hydrometer, especially at first; subsequently towels or handkerchiefs were used, but as there was no great abundance of these, they could not be changed

[1] That this is actually the case may easily be ascertained by observing small particles floating on the surface of the water. As soon as the instrument touches the surface these particles are suddenly driven outwards in all directions from the glass, and the water-film of the glass spreads as rapidly as if it had been oil — which it partly is —, and forms a new surface up to a certain distance from the instrument. Gradually as the latter is farther immersed, the area of this new surface grows, until it covers the whole of the water-surface in the cylinder. This is the case although the surface of the hydrometer may be apparently dry; if it be perfectly dry, this does not happen, but there is rather a tendency in the opposite direction; instead of giving off surface-film, the instrument is apt to carry the existing surface-film of the water down with it.

very often. This may, therefore, have helped to make the indications of the hydrometer higher than would otherwise have been the case, and attention has to be paid to this circumstance when the corrections of the instrument are determined.

e) *The influence of the adherence of grease to the surface of the hydrometer.*

If the hydrometer is covered with a thin layer of fat or oil this will naturally influence its indications in two ways. By increasing the volume of the instrument with a substance lighter than water, the indications of the hydrometer should be increased. By making the adhesion of the water to the glass surface of the stem less perfect at the water-line, the grease will cause an increase of the angle of contact, and thus impede the normal development of the meniscus, and will thus also increase the indication of the hydrometer. This has been fully acknowledged by previous authors[1].

In order to find out which of the two influences is the more effective, the following experiment was made. The whole of the hydrometer was rubbed with greasy fingers, and was thus given a thin coating of fat. It was then immersed in sea-water, the specific gravity, $S\frac{17{\cdot}5^0\,\text{C.}}{17{\cdot}5^0\,\text{C.}}$, of which was found by Mr. Hercules Tornöe, by the Sprengel pycnometer, to be 1·02534, and the following readings taken:

	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to 17·5° C.	Error of Observation.
The hydrometer rubbed all over with greasy fingers and then immersed.	8·47	1·024 78	1·024 99	+ 0·000 35
Hydrometer moved up and down, thermometer immersed and removed. .	47	52	73	61
Thermometer immersed and removed.	47	50	71	63
— — — —	52	49	71	63
Mean:			1·024 79	+ 0·000 55

[1] I do not here consider the effect which the oil of the hydrometer may produce by spreading over the surface of the water, and thus reducing its surface-tension. This effect may naturally be considerable, and will be mentioned later.

When the hydrometer was taken up, the greasy finger-marks were still equally visible. It was now carefully wiped dry, was again immersed, and the following readings were taken:

	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to 17·5° C.	Error of Observation.
Hydrometer wiped carefully and immersed	8·56	1·024 60	1·024 83	+ 0·000 51
Thermometer immersed and removed	61	42	66	68
— — — —	64	39	64	70
Mean:			1·024 71	+ 0·000 63

The hydrometer was taken up, its stem was carefully wiped dry, and was then rubbed with a greasy finger only at the water-line. When it was now immersed, the following readings were taken:

	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to 17·5° C.	Error of Observation.
The stem of the hydrometer rubbed at the water-line with a greasy finger, and hydrometer immersed .	8·71	1·024 71	1·024 97	+ 0·000 37
Thermometer immersed and removed	69	55	81	53
— — — —	70	48	74	60
— — — —	69	47	71	63
— — — —	71	41	72	62
Mean:			1·024 79	+ 0·000 55

It may be seen that the results are in every respect almost identical, whether the whole of the hydrometer has been covered with grease, or only the surface of the stem at the water-line. The maximum indication of the hydrometer obtained immediately after the immersion, is almost the same in both cases, 1·02499 and 1·02497, the difference of 0·000 02 being within the limit of error of observation. The other observations are very nearly the same; while the three intervening observations, taken with the clean hydrometer, give normal results, the mean error of the indications of the instrument being + 0·000 63. It may thus be said that *grease adhering to the surface of the body of the hydrometer has practically an altogether*

insignificant influence upon its indication, while *grease covering the surface of the stem at the water-line has a very appreciable influence,* producing a difference of + 0·00008 in the average result of a series of observations, and a still greater influence in the first single observations.

The latter do not, however, give much higher figures than a minimum of surface-tension, which will give indications of 1·02493 reduced to 17·5° C., the error being = + 0·00041, while it is = + 0·00035 in the above case.

In order to remove all traces of grease from the hydrometer, and to ensure a perfect wetting of the stem, I would recommend the careful cleaning of the instrument, and especially of the stem, by immersing it in a strong solution of potassium carbonate, or a weak solution of ammonia, rinsing it in pure water, and immediately before using it, wiping it dry with a towel that has been carefully cleaned from all oily or unctuous substances. Or the instrument might still better be rinsed with water of the sample that is going to be examined, without wiping the instrument before it is used.

f) *Difference when a water-sample is examined by the hydrometer at once, in a fresh state, or after having stood in the heated laboratory for some time.*

If cold water-samples containing much air be brought into a warm cabin or laboratory, and there examined at once by the hydrometer, the temperature of the water will begin to rise; it will be supersaturated with air, and air-bubbles adhering to the surface of the hydrometer will begin to form, tending to raise the instrument. The bubbles, of course, must be carefully removed, *e. g.* by wiping; but if they are very small, they are not easily discovered, and small, almost microscopic bubbles such as these, may influence the indication of the hydrometer appreciably. For this reason only, I consider it inconvenient to make the hydrometer-determinations in water that is supersaturated with air, and I think it important that the water-samples should at least have been heated to the temperature of the room for some time before the observations are made. But it is still better always to heat them to some higher temperature, make them give off their superfluous air by shaking the bottles, and then cool them down to the temperature at which it is desired to make the observations.

I would recommend a heating-box with a constant temperature, to be kept in the cabin or laboratory, or a warm water-bath or sand-bath, in which many bottles containing water-samples may be placed at once, and be heated to a certain temperature without any loss of time. By afterwards placing them in cold water or ice, the temperature may easily in a few minutes be brought down again to the desired point. If, moreover, the hydrometer be taken out of the water, and wiped carefully once or twice during a series of observations, as was always done on board the 'Fram', one may feel confident that no appreciable errors arising from air-bubbles will occur.

However, the influence of air-bubbles upon the indications of the hydrometer is much less than might at first be expected. In order to lift our instrument sufficiently to raise its indication by +0·00010, an air-bubble with a diameter of nearly 3 mm. would be necessary, and this is a larger bubble than is generally formed, and would be equivalent to a good many small bubbles of the ordinary size.

Appreciable errors arising from air-bubbles may, therefore, be confidently said to be altogether improbable in our observations.

I have, nevertheless, on several occasions noticed that by examining the water-samples at once when they were brought fresh into the cabin or laboratory, I often get appreciably higher determinations of their specific gravity by the hydrometer, than I do a day or two afterwards, when they have been standing in the heated room. The following example is instructive.

On April 19th, 1899, when the temperature of the air was about zero centigrade, a water-sample was taken from about 100 m. at Dröbak. It was brought into the laboratory of the Marine Biological Station, and was examined at once with the hydrometer Åderman No. 2. The temperature in the laboratory was between 10° and 11° C. The observations were made in the same manner as during the expedition[1]. The following determinations were made:

[1] See Memoir No. IX.

April 19th, 1899.	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to $\frac{17{\cdot}5^{\circ}\ C.}{17{\cdot}5^{\circ}\ C.}$	
	7·9 ° C.	1·026 43	1·024 85	
	8·0 -	52	95	Hydrom. moved up and down.
	05 -	50	94	— — —
	15 -	49	94	— — —
	20 -	52	97	— — —
	30 -	45	91	— — —
The hydrometer taken out and wiped dry.				
	8·64° C.	1·026 42	1·024 92	
	72 -	48	99	Hydrom. moved up and down in the water.
	86 -	39	92	— — —
	9·11 -	35	91	Stem wiped dry.
	13 -	40	97	
	13 -	39	96	
	13 -	35	92	
	18 -	38	95	
		Mean:	1·024 94	

On the following morning, the following determinations were made of the same water-sample:

April 20th, 1899.	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to $\frac{17{\cdot}5^{\circ}\ C.}{17{\cdot}5^{\circ}\ C.}$	
	11·62° C.	1·025 89	1·024 81	Hydrometer wiped dry.
	62 -	95	87	Hydrom. moved up and down in the water.
	61 -	99	90	— — —
	62 -	98	89	— — —
The hydrometer taken out and wiped dry.				
	11·74° C.	1·025 83	1·024 76	— — —
	73 -	84	77	— — —
	74 -	80	74	— — —
		Mean:	1·024 82	

On the third day, April 21st, I again examined the same water-sample, after having brought it to my home at Lysaker, and the following determinations were made:

April 21st, 1899.	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to $\frac{17{\cdot}5^0\ C.}{17{\cdot}5^0\ C.}$	
	7·46° C.	1·026 40	0·024 76	Hydrom. wiped dry.
	96 -	34	73	Hydrom. moved up and down.
Hydrometer taken out and wiped dry.				
	8·71° C.	1·026 28	1·024 79	
	86 -	24	77	Hydrom. moved up and down.
	96 -	26	80	— — —
			Mean: 1·024 77	

On three subsequent days we then have the following determinations by the hydrometer Åderman No. 2 of the same water-sample, being the means of several series of observations.

Mean of determinations of the first day . . . . . 1·024 94
— - — - - second - . . . . . 1·024 82
— - — - - third - . . . . . 1·024 77

As may be seen, there is a difference between the determinations of the same water-sample of the first day and the last, of no less than 0·000 17,

By two careful determinations by his Sprengel pycnometer, Mr. Hercules Tornöe found on May 16th, 1899, the specific gravity, $S\frac{17{\cdot}5^0\ C.}{17{\cdot}5^0\ C.}$, of this water-sample to be 1·025 54. By two determinations of the same water-sample, with another Sprengel pycnometer, I had previously, on May 1st and 6th, 1899, found its specific gravity to be 1·025 53, and as this determination is from an earlier date than Tornöe's, I accept it as the more accurate.

The apparent errors of the indications of Åderman No. 2, on the three dates mentioned above, are consequently as follows:

Correction of observations on the first day. . . + 0·000 59
— - — - - second - . . . + 0·000 71
— - — - - third - . . . + 0·000 76

On a previous occasion, on February 25th, 1899, a water-sample was sent from Dröbak to my home at Lysaker. There were at the time many degrees of frost outside, and the sample had a temperature of a few degrees above freezing-point when it was brought into my room. It was examined on the same day. The water was saturated with air, and air-bubbles readily formed in it during the observations. The following readings were taken:

February 25th, 1899.	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to 17·5° C.
Hydrometer wiped well and moved up and down .	14·30° C.	1·026 38	1·025 75
— moved up and down	65 -	50	94
— — — —	90 -	47	95
— — — —	15·05 -	47	6 00
— left alone for some time, many air-bubbles adhering to glass body . . .	16·10 -	37	(6 08)
— moved up and down carefully, all air-bubbles removed	50 -	22	6 02
Mean:			1·025 93

On March 9th, 1899, the same water-sample was again examined after having stood in my room during the intervening time, and having been heated to temperatures above the one at which the observations were made. The following ten readings were taken:

March 9th, 1899.	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to 17·5° C.
Hydrometer wiped carefully and immersed	14·50° C.	1·026 40	1·025 81
— moved up and down	60 -	33	76
— — — — and lifted out of the water and then slowly immersed.	90 -	38	86
— wiped and immersed.	15.30 -	22	78
— moved up and down.	40 -	18	76
— — — —	60 -	18	80
Stem of hydrom. wiped, immersed and left alone for some time	16·00 -	12	82
Hydrometer moved up and down	13 -	09	81
— — — —	20 -	12	85
— — — —	25 -	09	83
Mean:			1·025 81

On the following day, March 10th, 1899, six series of observations were made by the hydrometer, of the same water-sample, each series consisting of ten observations (making altogether 60 observations). The temperature of the water, and of the room, was now somewhat lower, between 13° and 16° C. The mean values of the indications of Åderman No. 2, reduced to 17·5° C., obtained by each of the six series of observations, were as follows:

March 10th, 1899.	Mean of the indications of Åderman No. 2, reduced to 17·5° C.
First ten observations	1·025 74
Second ten —	77
Third - —	78
Fourth - —	78
Fifth - —	75
Sixth - —	73
Mean of all sixty observations	1·025 76

Two days later, March 12th, three similar series of 10 observations each, taken at temperatures between 10° C. and 12° C., gave the following means reduced to 17·5° C.: 1·025 72, 1·025 81, and 1·025 77. But during the second series, the instrument was wiped with a piece of wash-leather instead of a towel, and this was evidently the cause of the higher mean given by that series[1].

A fourth series of seven observations was taken on the same day on a shaky table:

March 12th, 1899.	Temperature of the Water.	Indication of Åderm. No. 2.	Indicatiou reduced to 17·5° C.
Hydrometer wiped and immersed	11·10° C.	1·026 84	1·025 68
Hydrometer moved up and down	15 -	80	64
— — —	25 -	80	66
— — —, thermometer immersed and removed	35 -	78	65
Stem of hydrometer wiped and immersed	50 -	78	67
Hydrometer moved up and down	65 -	75	66
Thermometer immersed and removed	70 -	76	68
Mean:			1·025 66

[1] It may be that the wash-leather made the surface of the stem less clean, *e. g.* by fatty matter, and that the surface-tension has thus been reduced, and the angle of contact increased; if so, the greasy coating has probably not been totally removed in the third series.

This last determination must be considered to be the minimum indication of the hydrometer in this water-sample, as will be mentioned later, because the surface-tension of the water is raised to a maximum by the shaking of the table (see later).

We thus have the following mean determinations of the water-sample on the following dates:

				Reduced to 17·5° C.	Error of Åderm. No. 2.
February	25th,	1899,	when brought in cold and saturated with air	1·025 93	+ 0·000 51
March	9th,	—	after water-sample had been standing some time in warm room	1·025 81	+ 0·000 63
March	10th,	—	— — —	1·025 76	+ 0·000 68
March	12th,	—	not including the second series	1·025 75	+ 0·000 69
—	—	—	Minimum observations on shaky table .	1·025 66	+ 0·000 78

Mr. Hercules Tornöe has kindly determined the specific gravity $\left(S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}\right)$ of this water-sample by the Sprengel pycnometer, and has found it to be 1·026 44.

We thus find that the errors of Åderman No. 2 on the above-mentioned dates, have been those given in the last column of the table above.

I thought at first that these observations clearly proved that the gases contained in the water influence the indications of the hydrometer, probably by reducing the surface-tension of the water. This supposition seemed to be confirmed by the following observation. On April 20th, 1899, a water-sample was taken from 150 m. at Dröbak, its temperature *in situ* was 6·2° C. It did not contain as much gas *in situ* as the sample taken from 100 m. the day before. The temperature of the air was 4·5° C., and the bottle with the water-sample was left standing for some length of time in the sunshine before it was brought into the laboratory for examination. The mean of 17 determinations by the hydrometer, Åderman No. 2, made at temperatures between 9° and 10° C., reduced to 17·5° C., gave 1·025 76.

Eight observations the next day, at temperatures about 7° and 8° C., reduced to 17·5° C., gave 1·025 69.

By the Sprengel pycnometer, both Mr. Tornöe and I found the specific gravity of the water-sample to be 1·026 53. The error of Aderman No. 2 was accordingly:

On April 20th, 1899. . . . . + 0·000 77.
- — 21st, 1899. . . . . + 0·000 84.

The reason why there is so little difference between the results of these two days might be that the water has not been saturated with air on the first day, and its surface-tension has been far from its minimum on both days. The above observations show that on the last day it has evidently been very nearly at its maximum[1].

My later investigations have, nevertheless, convinced me that the above explanation does not hold good, as the gases contained in water seem, as a rule, to have no appreciable effect upon its surface-tension. We have, therefore, here to do with some other phenomenon. I think it is probable that air-bubbles, rising in water, have a tendency to reduce the surface-tension by bringing impurities or oily substances in the water to the surface. It may also be that the organisms in fresh water-samples have some tendency to reduce the surface-tension, perhaps by their death and decomposition.

Not having had time to go more closely into this question, I cannot offer any more satisfactory explanation at present.

g) *The influence of dust, etc., floating on the water-surface.*

It is a well-known fact that an extremely thin layer of oil or unctuous substance floating on the surface of the water raises the indication of the hydrometer considerably. The explanation is simply that the oil reduces the surface-tension of the water, by nearly substituting its own tension, which is about half that of the water.

It has, however, also been stated by several authors that dust and other substances, *e. g.* fibres from the towel, floating on the water-surface, would have a similar effect upon its surface-tension, and thus upon the indications of the hydrometer. I have made a few experiments to ascertain whether this is really the case; but I have come to the conclusion that if the dust contains no oily or similar substances which can spread and form a thin film over the water-surface, it has either no appreciable influence upon the surface-tension, or may even tend to increase it, by absorbing the possible unctuous impurities present there before. If, for instance, the ash of a cigar which has just been glowing, be strewn on the water-surface, it will, if any-

[1] The chief reason might be that this water contained very little organic life.

thing, increase its surface-tension. The dust of charcoal which has been heated, has either no effect upon the surface-tension, or, if this is not near its maximum, will increase it. On the other hand, the ordinary dust of an inhabited room immediately decreases the surface-tension, and so does the dust of ordinary cork; while the dust of charred cork, which has been glowing, has no such effect. The reason is evidently that cork, as well as the ordinary dust of a room, always contains oily or unctuous substances, the most minute traces of which are sufficient to reduce the surface-tension of water considerably.

h) *The influence of shaking the glass cylinder in which the determinations by the hydrometer are made.*

In order to secure a natural development of the meniscus round the stem of the hydrometer, I often tried tapping the outside of the glass cylinder, at the level of the surface of the water inside. I discovered that I could thus frequently make the hydrometer sink deeper, and if, in this manner, I produced violent disturbances of the water-surface, I could even diminish the indication of the hydrometer considerably. Subsequently, I discovered that by making my observations with the hydrometer on a shaky table, where the surface of the water in the cylinder was in almost constant and often violent motion, I could bring the indications down to a minimum.

I at first believed the explanation of this to be that the stem of the hydrometer was more perfectly wetted for some distance above the water-line by the ripples on the surface, and that thus the meniscus was more developed. But seing that the same effect could not be obtained even by repeatedly immersing the whole stem of the hydrometer, I soon found that this view could not be the correct one. The right explanation is evidently, that a fairly violent shaking produces disturbances of the water-surface, by which the surface-film is ruptured, and small superficial currents are constantly forming a fresh water-surface. Thus the surface-tension of the water is increased to its maximum, which again will reduce the indication of the hydrometer to its minimum.

The above-mentioned circumstance may be of some significance in series of determinations made by the hydrometer on board a ship in the open sea. The motion of the ship, as well as the vibration produced by the propeller, will form ripples on the surface of the water-sample in the glass cylinder,

and will thus tend to increase its surface-tension. This may explain the reason why many investigators have obtained lower determinations of the specific gravity of their water-samples on board their ship, than afterwards in their laboratory on land. It proves the necessity of determining the corrections of a hydrometer as nearly as possible in circumstances similar to those in which it has been used.

This effect of the motion of the ship may, however, to some extent be counteracted, if the water-samples are examined in a fresh state shortly after they have been taken, or at any rate, if they are examined at a rising temperature, as will generally be the case in the northern seas (cf. pp. 13—20).

i) *The effect upon the indications of the hydrometer, produced by immersion of a thermometer, or glass rod, in the water.*

During my researches on board the Fram, I soon discovered that the immersion of a thermometer in the water in the glass cylinder in which the hydrometer was floating, would, as a rule, raise the indications of the latter, but if the thermometer were removed, the indication would be reduced, and even more than it was first raised. Although I could not explain this fact, or partly gave it an erroneous explanation (cf. Memoir IX), I took precautions to avoid the errors caused in this manner as much as possible. In this respect, however, I was only in some measure successful.

After my return from the expedition, I studied this phenomenon more closely, and made a series of experiments to find out its true nature.

Several years ago, Admiral Makaroff had noticed the same effect produced by immersing a thermometer in the vessel in which the hydrometer is floating, and without attempting any explanations, he describes his observations in his important work, 'Le Vitiaz et l'Océan Pacifique', published in 1894, while we were on our expedition[1]. This phenomenon has subsequently been studied by Prof. Krümmel, who has tried to give an explanation of it[2].

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[1] S. Makaroff, 'Le Vitiaz et l'Océan Pacifique', St. Petersburg, 1894, p. 61, § 58. Before our departure, Makaroff had described his experiments in two papers written in Russian, which I had not met with: 'On the determination of the specific gravity of Sea-water', Journal of the Physico-chemical Society of St. Petersburg, vol. 23, 1891, pp. 1—64; and 'Some remarks on the Hydrometers of the Vitiaz', ibid.

[2] Otto Krümmel, 'Geophysikalische Beobachtungen'. Ergebnisse der Plankton-Expedition der Humboldt Stiftung, vol. I. e, 1893, pp. 66, 67, footnote. 'Ueber einige neuere Beo-

He believes that the immersed thermometer must cause a current in the water, flowing downwards along with the immersed instrument, and upwards in other parts of the water in the glass vessel; thus tending to lift the hydrometer; whilst the removal of the thermometer will produce a current in the opposite direction, tending to sink the hydrometer. Krümmel describes a series of experiments which he thinks prove the correctness of this explanation[2]. By direct observations, I was able to convince myself that no such regular currents, as the above explanation supposes, exist. By placing the glass cylinder containing sea-water and the hydrometer floating in it, in a window so that one can look through it towards the light, one can easily, by help of the many small particles floating in the water, follow in their smallest details the currents produced by the immersion or removal of a thermometer. It will then be seen that these currents are very complicated, rotating in all directions, and cannot generally help to lift the hydrometer. On the other hand, in a narrow cylinder, they are of comparatively short duration, and after a while the water may again be practically at rest, while the effect of the immersion or removal of the thermometer upon the indication of the hydrometer still remains unchanged,

The following experiment is very instructive. By placing weights on the stem of the hydrometer, or by changing the temperature of the water, I arranged it so that the hydrometer would just sink and be totally immersed in the water. But as there must be a slight difference of temperature, perhaps as much as 0·1° C., between the upper and lower water-strata in the cylinder, the hydrometer would perhaps not sink to the bottom, but stop midway in the water, and remain in that position. Extremely little was now wanted to make it rise to the surface again, or sink to the bottom; and it is clear that if the currents created by the immersion of a thermometer had the slightest effect upon the position of the hydrometer, it would here be demonstrated beyond doubt. I immersed first one thermometer, then another, then a third, and I removed them again one after the other, but there was no difference to be seen in the position of the hydrometer, except that the

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bachtungen an Aräometern', Ann. der Hydrogr. und Marit. Meteorol., Nov. 1894, separate copy, p. 3.

[1] Dr. G. Schott has also accepted this explanation, see 'Petermann's Mitteilungen, Ergänzungsheft 109, 1893, p. 19, where he gives a diagrammatic sketch to demonstrate the course of this hypothetical current.

water was heated a little by the warmer thermometers, and the hydrometer sank slowly to the bottom. This experiment was repeated several times, but always with the same negative result. If, however, a part of the stem of the hydrometer projected above the surface of the water, in the ordinary way, the immersion or removal of the three thermometers had a very considerable effect upon the position of the hydrometer, changing its indications $\pm$ 0·0002, or $\pm$ 0·0003, or perhaps even more. But as soon as the top of the stem of the hydrometer was only half a millimeter or less below the water-surface, there was no effect visible.

This experiment proves clearly that *the changes in the position of the hydrometer in the water, caused by the immersion or removal of a thermometer (or other body), must be owing to some changes produced in the properties of the water-surface.* The currents thus produced in the water have no appreciable and lasting influence upon the position of the hydrometer.

This experiment also convinced me that it would be a simpler and very much more accurate method for determining the specific gravity of sea-water, to use totally immersed hydrometers, and to determine the temperature of the water in which they sink, instead of using the ordinary hydrometers (see later).

II.

THE INFLUENCE OF THE SURFACE-TENSION OF THE SEA-WATER UPON THE INDICATIONS OF THE HYDROMETERS.

All my observations and experiments just described led me to the conclusion that the cause of the apparent uncertainty of all determinations of specific gravity made with the hydrometer had to be sought chiefly in peculiar changes in the properties of the water-surface, and that all other causes of irregularities were of little account compared with this.

I felt, moreover, convinced that if I could only come to a certain understanding of the true nature of these apparently quite irregular and uncontrollable changes, which I expected to be changes in the surface-tension of the water, I should be enabled to correct in a more satisfactory way my determinations of the specific gravity of the water of the Polar Sea, and we should also, on the whole, be enabled to make future determinations with the hydrometer considerably more acurate and trustworthy than they have hitherto been.

I have therefore made series of experiments of various kinds in order to find this out.

That the surface-tension of water is subject to certain variations might have been concluded from the fact that hardly two physicists have been able to arrive at the same values for the surface-tension of water or other liquids. It is also a well-known fact that the surface-tension, *e. g.* of water, is soon reduced if the water-surface remains undisturbed for some time. The surface-tension has, however, an important influence upon the position of an ordinary hydrometer in water, by attracting its stem, and thus lowering it. The

force with which the surface-tension attracts a hydrometer downwards will depend upon the circumference of its stem at the water-line, and will be equal to the weight of the meniscus formed round the latter.

If we call the weight of this meniscus v, we have:

$$v = 2\pi r \alpha$$

where r is the radius (1/2 diameter) of the stem of the hydrometer, and α the surface-tension of the fluid.

According to Dittmar's investigation[1] the surface-tension of ordinary sea-water should be $\frac{402}{456}$ of that of distilled water. This result seemed to be in contradiction with the results of the investigations of other physicists, viz. that the surface-tension of solutions of salts is higher than that of distilled water. In a letter (of February 27th, 1899) Prof. Otto Krümmel kindly informs me that he has lately made this matter the subject of careful investigations, and has, as might be expected, found that the surface-tension of sea-water increases in direct ratio to its salinity. He has arrived at the following empirical formula for the calculation of the surface-tension of sea-water:[2]

$$\alpha = 7{\cdot}709 - 0{\cdot}01783\,t + 0{\cdot}00224\,p.$$

where t is the temperature of the water in degrees centigrade, and p is its salinity per mille (grams of salt per 1000 grams of liquid).

If we assume $p = 35$ ‰, we find by this formula:

$\alpha = 7{\cdot}61$ at 10° C.

$\alpha = 7{\cdot}52$ at 15° C.

If r is 2·2 mm. we find accordingly the weight of the meniscus to be

100·4 milligram at 10° C.

99·3 milligram at 15° C.[3]

The surface-tension of the water should accordingly make the hydrometer sink sufficiently to increase its volume when immersed, with a quantity equal

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[1] 'Challenger Reports, Physics and Chemistry', vol. I. p. 83.

[2] Although Prof. Otto Krümmel has not yet had an opportunity of publishing his investigations, he has had the great kindness to place this result at my disposal. I offer him my sincere thanks for this, as well as for other valuable advice he has given me.

[3] In Krümmel 'Ueber einige neuere Beobachtungen an Aräometern', Ann. d. Hydr. u. Marit. Meteor. Nov. 1894, separate copy, pp. 6, 7) there are some mistakes, as the weight of the meniscus is stated to be 8 mg., 7 mg., 0·1104 g., instead of 80 mg., 70 mg., and 0.104 g. The last value is evidently meant to be for distilled water and not for sea-water, but the value of the surface-tension used, viz. 8·25, is certainly too high for calculations of this kind.

to these weights of the meniscus. Water with a salinity of 35 ‰ has at 10° C. a specific gravity $\left(S\frac{t}{4^{\circ}\text{ C.}}\right)$ of 1·0269, and at 15° C. of 1·0259. The surface-tension, or the meniscus, should consequently sink the hydrometer in such water

at 10° C. a volume = 97·8 cubic millimetres,
at 15° C. a volume = 96·8 cubic millimetres.

As the diameter of the stem is 4·4 mm., the hydrometer would therefore sink

at 10° C., 6·44 mm.
at 15° C., 6·37 mm.

As the distance between the division-marks on the stem is 0·823 mm., this would be equal to to 7·8 and 7·7 degrees of the scale, or a difference in the indication of the hydrometer of 0·00078 and 0·00077.

The greatest differences produced in the indications of the hydrometer by immersion or removal of a thermometer were, however, 0·00030, or could even approach 0·00040. As this is as much as about half of the whole influence of the surface-tension under ordinary circumstances, I did not at first believe that it could be caused solely by variations in the surface-tension (or the size of the meniscus), as I did not consider it possible that this could vary so much.

According to Lord Rayleigh's investigations[1], the surface-tension, α, of water should, by "saturating" its surface with oil, be reduced from 7·55 mgr. to 4·07 milligrammes. By addition of a drop of oil to the surface of the water, the hydrometer Åderman No. 2 should consequently be raised sufficiently to increase its indication about + 0·00036. This seems to agree well with what has actually been observed.

Thinking that there was a possibility that the *meniscus on the water-line round the inside of the glass cylinder* in which the observations are made, might somehow perceptibly influence the position of the floating hydrometer, and that changes in its form might be produced by the rise and fall of the water, when a thermometer was immersed and again removed, I made the following experiment in order to ascertain whether the rise and fall of the water in the cylinder had any effect upon the level of the hydrometer, if the water-surface were not disturbed by the introduction of another body.

[1] Lord Rayleigh, Philos. Magazine, 5 series, vol. XXX, p. 386.

I placed a glass siphon in the cylinder. By a piece of India rubber tubing, this siphon communicated with a glass vessel, which was filled with water of the same kind as that of the cylinder. By lowering or raising this vessel, I could thus lower or raise the level of the water in the cylinder at will, without disturbing the water-surface. The specific gravity $\left(S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}\right)$ of the water-sample used was determined by Mr. H. Tornöe by the Sprengel pycnometer to be 1·026 44. I made the observations given in the following table:

	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to 17·5° C.	Error of Observation.
Hydrometer wiped and moved up and down in the water	16·9 ° C.	1·026 12	1·026 00	+ 0·000 44
The water-surface in the cyl. lowered.	9 -	11	5 99	45
— — lowered still more.	95 -	10	5 99	45
— — raised.	17·05 -	10	6 01	43
A thermometer immersed and removed	3 -	5 98	5 94	50
Hydrometer moved up and down in the water	4 -	6 08	6 06	38
Thermometer immersed and removed, the water-surface shaken by tapping the outside of the cylinder. . . .	6 -	5 74	5 76	68
Water-surface lowered.	65 -	75	78	66
— — raised.	8 -	80	86	58
— — raised and the siphon removed	9 -	68	76	68
— — shaken by tapping the outside of the cylinder.	9 -	66	74	70
A thermometer immersed and removed.	9 -	65	73	71
— — — , and also the other thermometer by which the water-temperatures were measured removed	18·1 -	62	74	70

Although the indication of the hydrometer is near its maximum at the beginning of the experiment, it is seen that a fall of the water-surface twice repeated is only able to change the indication as much as — 0·000 01. It is moreover seen that while a considerable fall and rise of the water-surface in only one observation (the 9th), when the indication beforehand had been brought down to a minimum, is able to change the indication of the hydrometer as much as 0·000 08, and as a rule only 0·000 01 or 0·000 02[1], the

[1] The reason why the indication of the hydrometer is raised by raising the water is

immersion or removal of a thermometer, combined with tapping the outside of the cylinder, reduces the indication in one case 0·000 30 (in the 7th observation), and in another case, when the indication had already been brought down by the experiment just mentioned, to 1·026 86, the removal of the siphon, along with the tapping, etc. brought it down to 1·025 73, that is — 0·000 13.

It may thus be understood that the lowering or raising of the water-level in the cylinder has but little influence upon the position of the hydrometer compared with that which is produced by the removal of a glass tube (or thermometer) or by shaking the water-surface. It is not therefore probable that the meniscus round the inner wall of the glass cylinder has any appreciable influence upon the indication of the hydrometer.

I also convinced myself of this in another way. I brought the indication of the hydrometer up to a maximum, and then passed the end of a glass-rod round the margin of the water-surface, thus moistening the inner wall of the glass cylinder a good distance up from the surface, and allowing the meniscus to develop naturally; but there was no change of any importance in the indication of the hydrometer. The indication given in the first instance was 1·025 94 (reduced to 17·5° C.) and in the second 1·025 91, but as soon as a thermometer was immersed and removed, the indication given was 1·025 66 (reduced to 17·5° C.), or a difference of 0·000 25.

After all, however, according to these experiments, there was still a possibility that the meniscus inside the glass cylinder might have some slight influence upon the level of the hydrometer. As far as I can see, there are only two ways in which this can happen, either *(a)* the pressure in the water must be altered by the shape of the meniscus, or *(b)* the meniscus inside the cylinder may have some influence upon the meniscus round the stem of the hydrometer.

a) If the surface of the water in the glass cylinder be absolutely plane, *i. e.* has no meniscus along its margins, then the surface-tension can have no influence upon the pressure in the water unless for the meniscus round the stem of the hydrometer. If the water-surface is concave as in a capillary

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evidently that the water-film on the wet inner wall of the cylinder has a low surface-tension, and when it spreads on the top of the rising water, immediately reduces the surface-tension of the latter.

tube, the surface-tension will reduce the pressure in the water; if the surface is convex it will increase it. The changes in the pressure caused in this way by the surface-tension must be equal to the distance it would be able to raise or to depress the surface of a water-column in a tube of the same diameter as the glass cylinder. For instance, if the surface-tension in a glass tube (or glass cylinder) were able to raise the surface of the water in the centre of the tube one millimetre, this proves that the pressure on each square millimetre of the surface near the centre must have been reduced as much as one milligramme. But such a reduction of the surface-pressure would lower, to the same extent, viz. one millimetre, the level of the hydrometer floating in the water with its stem above the surface, provided that the meniscus round the stem be not altered, because the influence on the hydrometer by the reduction of the pressure is equivalent to an increase in its weight amounting to the total change of pressure on an area equal to that of the transverse section of the stem at the water-line; but as this change of pressure is one milligramme on each square millimetre, the hydrometer should sink 1 millimetre, if we suppose the specific gravity of the liquid to be 1·0.

It will thus be understood that if the diameter of the glass vessel in which the hydrometer is floating is very narrow at the water-line, forming a capillary tube round the stem, then changes in the pressure produced in this way by the surface-tension, may cause considerable changes in the level of the hydrometer. But as soon as the diameter of the water-surface reaches as much as 2 centimetres, the changes of pressure produced in this way will practically be of no importance. In a tube with a diameter of 2·8 cm. the surface-tension will not be able to raise the water-surface in its centre more than 0·09 mm., and its influence upon the level of the hydrometer, caused by changes in the pressure only, will consequently altogether not be more than this. In a glass cylinder with about double that diameter, the changes caused in this way can hardly be observed, and would in our case only be perceptible in the sixth decimal place of the specific gravity.

b) It is a well-known phenomenon that when two plates are immersed in a liquid near each other, they will approach one another if the meniscus formed on their inner sides have the same form, *i. e.* are both concave or both convex. But if one of the menisci is concave and the other convex,

the plates will be repelled from one another. It might thus be expected that a convex meniscus round the side of the glass cylinder instead of a concave one would lift the hydrometer a little, but at most it could not be more than double the height to which the surface-tension could raise the level of the water in a tube with the same diameter as the cylinder, and this, as we have seen, is so insignificant that it may be left out of consideration.

It may thus be understood that the form of the meniscus round the side of a glass cylinder of a diameter of 5 cm. or more, can have no appreciable influence upon the indications of the hydrometer, and may be disregarded.

In order to ascertain whether any appreciable change was produced in the pressure of the water by the immersion or removal of a thermometer or a glass rod, Prof. Torup and I made the following experiment. A narrow glass tube was placed in a vertical position in the water-surface of the glass cylinder, and the height of the water-column inside the tube was read off by a kathetometer; a glass rod was now introduced into the cylinder, and again removed. The height of the water-column in the tube was read off again. By repeating this several times it was ascertained that the water-column inside the tube did actually sink a trifle after the immersion and removal of the glass rod. This shows that the pressure in the water-surface outside the tube had actually been reduced. Although our experiment was not so arranged as to allow us to measure accurately changes of such minute magnitude as this reduction, it was sufficient to prove that the changes in the level of the hydrometer, produced by an immersed or removed glass rod, could to no appreciable extent be referred to changes in the pressure in the water.

In order to examine whether the condition of the inner surface of the glass cylinder had any influence upon the indications of the hydrometer, I first made some observations with the hydrometer in the cylinder[1], using a water-sample, the specific gravity $\left(S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}\right)$ of which Mr. Hercules Tornöe had determined to be 1·025 34 by the Sprengel pycnometer. I then cleaned and scrubbed the inside of my cylinder carefully with soap and strong lye, and made a new series of observations. The following readings were taken:

[1] The glass cylinder was then, February 10th, 1899, in the same state in which it had been used the whole time, without having been cleaned with anything but water.

Before the glass cylinder had been cleaned.

	Temperature of the Water.	Indication of Åderm. No. 2.	Indication reduced to 17·5° C.	Errors of Observation.
Hydrometer wiped dry.	17·88° C.	1·024 75	1·024 83	+ 0·000 51
Thermometer immersed and removed.	78 -	60	66	68
— — —	76 -	60	65	69
— — —	86 -	63	70	64
Hydrometer wiped dry and immersed slowly.	18·01 -	69	79	55
Thermometer immersed and removed.	06 -	52	63	71
— — —	06 -	50	61	73
Mean:			1·024 70	+ 0·000 64

After the glass cylinder had been cleaned.

Hydrometer wiped.	13·97° C.	1·025 35	1·024 66	+ 0·000 68
Thermometer immersed and removed.	14·19 -	25	60	74
— — —	31 -	19	57	77
— — —	56 -	16	58	76
Hydrom. wiped, immersed slowly. . .	15·21 -	20	74	60
Thermometer immersed and removed	39 -	4 98	56	78
— — —	49 -	97	57	77
Mean:			1·024 61	+ 0·000 73

It may be seen that there is a difference of 0·000 09 in the mean of the indications obtained before and after the cleaning of the inside of the cylinder.

I now wished to see what influence it would have if the glass cylinder were lined inside along the water-line with filter-paper, as I thought this would secure a full and uniform development of the meniscus under all circumstances. The following observations were made in sea-water with a specific gravity $\left(S\frac{17{\cdot}5^{0}\,\text{C.}}{17{\cdot}5^{0}\,\text{C.}}\right)$ of 1·026 44[1]:

[1] According to determinations with the Sprengel pycnometer, which Mr. Hercules Tornöe has kindly made for me.

	Indication of Åderm. No. 2 referred to 17.5° C.	Error of Observation.
Hydrometer wiped dry and immersed; mean of several observations	1·025 78	+ 0·000 66
A thermometer immersed and removed several times	71	73

The upper part of the glass cylinder was now lined inside with pieces of filter-paper, reaching to a short distance below the water-surface.

Hydrometer wiped and immersed, mean of several observations	1·026 00	+ 0·000 44
A thermometer immersed and removed several times	84	60
Hydrometer moved up and down several times . . .	608	36
All pieces of filter-paper removed, one by one . . .	590	54
A thermometer immersed and removed several times	71	73

It will be seen that by the immersion of the filter-paper the indications of the hydrometer are considerably increased as a whole; but at this higher level, the immersion or removal of a thermometer has the same effect as under ordinary circumstances. It will moreover be seen that the removal of the filter-paper again reduces the indications of the hydrometer, and that after the removal of all the pieces, and after the thermometer has been immersed and drawn up several times, the indication of the hydrometer is brought down to the same minimum 1·025 71, (giving an error of the instrument of + 0·000 73), as that which was attained before the filter-paper was introduced.

I now tried the effect of a ring of filter-paper floating on the surface of the sea-water, and I obtained the two following readings, reduced to 17·5° C.: 1·026 03 and 1·026 06. It appears, accordingly, that the filter-paper has the same effect in this manner, as when placed round the sides, as above.

I have tried dry pieces of filter-paper of various kinds, but they have all more or less the same effect, even though they are carefully cleansed by various methods; while immersed dry pieces of ordinary, clean writing-paper have the opposite effect. It seems probable that the filter-paper somehow contaminates the water-surface, thus reducing the surface-tension; but this contamination is again removed, more or less, by the removal of the paper (see later).

Both Makaroff and Krümmel have already pointed out that the smaller the diameter of the glass cylinder in which the observations are made, the

greater is the effect that an immersed thermometer has upon the indications of the hydrometer[1]. Having found, as indicated above, that this influence of an immersed or withdrawn thermometer, or glass rod, is confined to the free surface of the water, it seemed probable that only the area of this surface, *i. e.* the diameter of the vessel at the water-line, is of importance, while the diameter or volume of the glass vessel is of little account. By trying glass vessels of various shapes, this supposition was fully confirmed. An immersed thermometer had considerably less effect upon the indication of the hydrometer, in a glass cylinder that had a somewhat smaller diameter in its lower part than the one used before, but whose upper end widened out abruptly, so that the water had a much larger free surface. The two cylinders contained very nearly the same quantity of water[2].

I now tried the effect of placing a glass tube round the stem of the hydrometer, with its lower end just a little below the surface of the water. If a thermometer was immersed or withdrawn outside the glass tube, it had very little effect upon the position of the hydrometer; it seemed as if the glass tube protected the hydrometer from the disturbing influence of the thermometer. But if the thermometer was immersed and removed within the tube, the effect was very much greater, increasing with a diminution in the diameter of the tube.

All the experiments recorded above, had convinced me that by immersing a glass rod or other body in the water, or by again withdrawing it, some change is produced in the properties of the water-surface, and probably in the surface-tension.

I happened to speak to my friend, Prof. Birkeland, about some of my experiments. He told me that the sculptor, Mr. *O. Castberg,* had some time before shown him some highly interesting experiments, which were evidently based on changes in the surface-tension of water, and which in several respects had a great resemblance to mine. He thought I ought to see them as they might help me to form a clearer conception of the problem.

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[1] See Krümmel, Ann. der Hydr. u. Marit. Meteor., Nov. 1894.

[2] That the ratio between the volume of the immersed body and that of the vessel is, to a certain extent, of no importance, may be inferred from the fact that the immersion of a plate of extremely thin glass or mica (or paper), whose volume may here be left out of consideration, may have a greater effect upon the hydrometer, than an immersed glass rod of considerable volume, but with a smaller surface than the plate.

Upon Birkeland's request, Mr. O. Castberg had the great kindness, in May, 1899, to show me his ingenious and beautiful experiments, which in less than half an hour brought me nearer to the solution, than weeks of work had previously done. I take this opportunity to express to Mr. Castberg my sincere gratitude for the valuable assistance he has thus rendered me. With his permission, I shall here mention some of his experiments which are of interest with regard to our present subject.

Mr. Castberg had made himself a kind of hydrometer or float of a piece of cork, below which were fixed some nails as weights. But instead of the ordinary cylindrical stem, this instrument had a very thin plate of sheet metal, which naturally has a very much larger surface as compared with its volume. This hydrometer was, therefore, exceedingly sensitive to any changes in the surface-tension of the water in which it was floating[1].

By immersing objects in the water[2] in which this hydrometer was floating, Castberg could easily alter its level. But here again he used thin plates of metal, or ordinary paper, instead of the cylindrical thermometer or glass rod, and the effect was materially increased, the changes in the level of the hydrometer amounting to several centimetres. There was, however, a striking difference in the effect of the immersed plates, according to whether they were dry or wet. If dry plates of metal, or still better dry paper, were immersed, the hydrometer would invariably sink deeper and deeper with each plate or piece of paper immersed. The magnitude of the sinking was to a certain extent proportional to the area of dry surface — of paper or plate — passing down through the water-surface. This went on until the hydrometer had sunk to a certain lowest level, when it would sink no more. If the whole of an immersed paper, or piece of paper, had passed below the water-surface, it made no difference whether it remained there, or was allowed to sink to the bottom;

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[1] Castberg's instrument resembles in this respect the hydrometer with a stem of mica, used by Marangoni, and which he made to rise 12 centimetres by reducing the surface-tension with panamine. See Rivista scientifico-industriale de Guido Vimercati, Florence, 1880. (Not having had an opportunity of seeing this paper, I have here cited from Violle, Cours de Physique, vol. I, p. 645, Paris, 1884).
Castberg did not, however, know of Marangoni's experiments; in fact he had come upon the idea of his experiments without knowing anything of what had been published on the subject.

[2] The ordinary tap-water of Christiania was used for these experiments. Distilled water would, however, give the same results.

the hydrometer remained in the same position until the plate was again drawn up through the water-surface, when the hydrometer would sink still deeper, as long as it had not reached its lowest level.

If wet plates of metal, or sheets of paper, (that have been dipped in the same water) are immersed in the same manner as the dry ones, they have exactly the opposite effect; the hydrometer will rise higher and higher for each plate immersed, and the magnitude of the rise is to a certain extent proportional to the area of wet surface passing down through the surface of the water. This goes on until the hydrometer reaches a certain highest level, after which it rises no more. If the plates are again drawn up through the water surface and removed, the hydrometer will again sink in the same ratio as that in which it had previously risen, the changes in its level — always within a certain maximum and minimum — being proportional to the superficial area of the plates passing through the water-surface.

I made the following experiment. A good-sized piece of wet paper was immersed, making the hydrometer rise to a very high level. The paper was allowed to sink to the bottom of the vessel. With a pair of forceps, I there folded and rolled it into a small lump, which exposed a very small surface to the water, and in this shape the piece of paper could now be taken up through the water surface without effecting any appreciable sinking of the hydrometer, which practically remained floating in the same high position it had acquired by the immersion of the wet paper.

Castberg's instructive experiments have largely helped me to find what I consider to be the right explanation of the strange changes in the indications of the hydrometer. I only regret that I did not find this explanation on board the Fram, for in that case we should certainly have known the specific gravity of the water of the North Polar Basin, with a much higher degree of accuracy than we do at present, probably to one more decimal-place.

I now understand that we have here the same phenomenon that many physicists have noticed before in another and wider form, viz. that the surface-tension of water decreases after the surface has been free and exposed to the air for some time; and if such a surface be made fresher by expansion, its tension is again increased.

Castberg's experiments, as well as those of Makaroff, Krümmel, and myself, showing the effects of immersing and withdrawing a thermometer in

the water in which the hydrometer is floating, are in fact very similar to the experiment of *Blondlot* (1886)[1], who made a drop of oil, floating on the surface in a glass of water, increase its diameter, by slowly drawing a piece of immersed paper out of the water; but if he again immersed the paper slowly, the diameter of the oil-drop decreased. In the first instance, he evidently increased the surface-tension of the water by making a fresher surface, and the oil consequently spread more; in the latter case, the results were reversed.

That immersed dry or wet surfaces actually change the surface-tension of water, I have also proved by the following experiment. I placed two plane glass plates in ordinary fresh water, so that they formed an acute angle with each other, their vertical edges on one side being close together. The water would now rise, and form the well-known curve between the plates. If I immersed dry or wet pieces of paper[2] in the water at the open side of the plates, I could make the water between them rise or fall considerably according as the paper immersed was dry or wet; when the pieces of paper were drawn up through the water-surface, the water between the plates would always rise.

By watching motes on the surface of the water, — it may be distilled water, ordinary fresh water, or sea-water — one can easily see what takes place when a dry or a wet body is immersed If a dry body[3], *e. g.* a piece of dry paper, be immersed, a somewhat convex meniscus is formed round it, and as the paper passes downwards, the surface-film of the water is, as it were, attracted and drawn down with the paper; the motes can be seen streaming towards the paper from all sides, as if they were being sucked in. If the paper be again slowly lifted up through the surface, a similar phenomenon is observed. A concave meniscus is now formed round the paper; the surface-film streams towards it from all sides, and is lifted, adhering to its surface. In both cases, the film covering the water-surface is carried away by the paper, in the former case downwards, in the latter case upwards, and a more or less new and fresh water-surface must consequently

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[1] Journal de Physique (2), vol. V, 1886, p. 456.

[2] The paper is of course always wetted with water of precisely the same kind as that in which it is immersed.

[3] The surface of this body should not be absolutely clean, or free from all greasy matter; for then it will at once be perfectly wetted by the water, and a concave meniscus formed round it.

be formed; but this should increase the surface-tension, as we have also seen it do to a considerable degree.

If, however, we again immerse the wet piece of paper, which has just been lifted out of the water, exactly the opposite phenomenon will be observed. As soon as the wet paper touches the water-surface, the latter suddenly streams away on all sides, and the extreme film covering the water-layer of the paper spreads rapidly over the water-surface. As it passes down, the paper will gradually give off the whole of its thin, extreme surface-film[1] to the surface of the water, which it will very soon cover entirely. At the same time we have seen that the surface-tension of the water is diminished, and the hydrometer will rise accordingly.

Hence we may conclude that if, by immersion of a wet body, *additional exposed surface-film is spread over a recently formed water-surface, its tension is diminished.* If the paper be again lifted out, the surface-film is carried away, and the tension is increased as in the previous instance.

We have moreover seen that within a certain limit, the *changes effected in the surface-tension were proportional to the area of exposed water-film which was added to, or carried away from, the surface of the water.*

If a water-surface be left undisturbed for some time after its tension has been brought to a maximum or a minimum, the tension will gradually assume a mean value. If we call the maximum 8, and the minimum 4, this mean value will be at about 6·2, according to observations with my hydrometers in sea-water.

These facts will, I think, explain fairly well the changes in the indications of the hydrometer, effected by the various experiments previously described. The reason why the immersion of a thermometer was assumed always to increase the indications of the hydrometer, is that the surface of the thermometer was generally moist, or impure, when it was immersed. I have satisfied myself that the immersion of a glass rod with a perfectly dry, and nearly clean, surface, round which is formed a somewhat convex meniscus, may increase the surface-tension, and diminish the indication of the hydro-

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[1] That the film given off can be very thin, may be concluded from the fact that a glass plate, which is wiped until it is apparently dry, may give off surface-film in a similar way, as long as there is the slightest trace of moisture adhering to it, and may reduce the surface-tension of the water in the same manner (cf. foot-note, p. 10).

meter; but as there is little friction between the water and a fairly clean glass surface, the latter will not carry away much of the water-surface, and the diminution caused in the indication of the hydrometer will not be very appreciable[1]. The immersed glass rod will also cause the water to rise in the vessel, whose wet inner wall will give off exposed water-film to the surface of the water column, thus reducing its tension.

When a rise or fall of the water-surface in the glass cylinder causes some more or less appreciable changes in the indications of the hydrometer (see p. 28), these are due to the addition of exposed water-film to the water-surface from the wet inner wall of the cylinder during the rise of the water, or to the removal of surface-film by the glass surface of the cylinder during the fall of the water.

We saw (p. 29) that the end of a glass rod passed round along the inner wall of the glass cylinder at the water-line would change the indication of the hydrometer — 0·00003. The explanation of this is evidently that by dipping in, and passing round, the end of the glass rod, the water-surface has to some small extent been disturbed, and new water-surface partly exposed; and when the glass rod is again withdrawn, it will carry away a little of the surface-film. The reason why a perfectly clean surface on the inner wall of the glass cylinder diminishes the indications of the hydrometer (see p. 32), is evidently that the inner wall of the cylinder has, before the cleansing, been a little greasy, and minute quantities of grease may thus have been given off to the water-surface, diminishing its tension.

The reason why a glass ring or tube surrounding the stem at the water-line (see p. 34) seemed to protect the hydrometer against the influence of an immersed thermometer, as long as this was immersed outside the tube, but seemed to increase its effect when it was immersed inside the tube, is evidently that the diminution or increase of the surface-tension effected by the immersed or withdrawn thermometer, could not reach the water-surface surrounding the stem of the hydrometer, as long as this was separated by the tube from the surface in which the thermometer was immersed; while on the other hand, if the thermometer be immersed inside the glass tube, the latter will materially

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[1] If a body with a perfectly clean, smooth surface, *e. g.* a platinum plate previously heated red-hot, be immersed, it has no perceptible effect upon the surface-tension.

diminish the area of water-surface influenced by the thermometer, and will increase its effect accordingly.

The fact that the glass tube surrounding the stem of the hydrometer does not protect it completely against the influence of a glass rod immersed outside it, is easily explained, as a slight rise or fall of the water-surface inside the narrow tube, produced by the immersion or removal of the glass rod outside it, is sufficient to change the surface-tension of this small area by the water-film received from, or given off to, the inner wall of the tube. The immersion of a narrow dry or wet glass tube round the stem will therefore also greatly influence the indication of the hydrometer; and by lowering or raising the glass tube, we can inversely make the hydrometer rise or sink.

It may seem strange, that the immersion and subsequent removal of a glass rod or thermometer should, as a rule, increase the surface-tension, although they may be wet before they are immersed. It ought, however, to be remembered, that if the surface-tension is low, the immersion of a wet glass rod will not be able to diminish the tension much more, while the removal will have its full effect; therefore we see that the immersion and subsequent removal of a thermometer has always an effect, and generally a considerable one, if the indication of the hydrometer be near its maximum, while the effect is very uncertain and doubtful if it be near its minimum. On the other hand, by the immersion of a rod, the water-surface is put in motion and stirred, which, as we have seen before, has a diminishing effect upon the indications of the hydrometer. And finally, the water-film added by the immersed rod may just have been formed, and its surface-tension is not therefore near a minimum; while the water-surface which is extended by the removal of the rod will acquire a high tension.

All this leads to the conclusion that it should be easier to produce a maximum of surface-tension than a minimum, and that consequently the minimal indications of the hydrometer should be the more uniform, and the determinations obtained in this way should be more accurate and trustworthy. This agrees well both with my own experience and that of others.

III.

THE SOURCE OF THE PROGRESSIVE DIMINUTION OF THE SURFACE-TENSION OF WATER AND AQUEOUS SOLUTIONS.

Laplace[1] pointed out that there may be a great difference between the determinations of surface-tension made in capillary tubes; in some cases, the column of water may, in the same tube, rise twice as high as in other cases. Many other physicists have had the same experience. *Brewster* pointed out[2] that the disagreements between the determinations of the surface-tension by celebrated physicists are even greater than the differences found by Laplace, the values of the surface-tension varying from 2·1 to 5.3, while *Poisson*[3] maintains that the determinations made by *Gay Lussac* harmonise well with one another.

Many physicists have also observed that it is a recently formed water-surface which gives the highest values of the surface-tension. *Frankenheim* (1836) observed that the surface-tension was reduced after a time[4]. *Hagen* states (1846) that the fresher the surface of the water, the higher does it rise in a capillary tube. "Bringt man Theilchen aus dem Inneren an die Oberfläche, so zeigt sich die Capillärerscheinung am auffallendsten, aber in der Zwischenzeit von einer halben Minute ist sie schon merklich geringer geworden".[5] This reduction of the surface-tension will even go on for several days[6]. Hagen also observed that a drop of oil would not spread on a water-

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[1] Laplace, Mécanique Céleste, Suppléments au Xième livre, 1806.

[2] Edinburgh Encyclopædia. vol. V, 1830.

[3] Nouvelle théorie de l'action capillaire, Paris, 1831.

[4] Pogg. Ann. der Phys. und Chem., vol. XXXVII, 1836, p. 411.

[5] Pogg. Ann. der Phys. und Chem., vol. LXVII, 1846, p. 159.

[6] Hagen's statement (l. c. p. 159) that the water between two parallel plates sinks lowest when the water is boiling, and remains almost equally low after it has again been cooled down, evidently refers to another phenomenon, concerning which see later.

surface that had remained undisturbed for several hours or days, even if the surface had been protected from falling dust by a glass cover. This proves clearly that the surface-tension of the water had been greatly diminished; for if it be fully developed, the oil will spread immediately. Hagen could not obtain the maximum of surface-tension by adding fresh water, and he assumed that the surface-film remained the same, and was not renewed in this manner. If, however, he removed the water-surface between two parallel plates with thick, clean blotting-paper, he could easily increase the surface-tension to its maximum. He also pointed out how difficult it is to obtain identical values of the surface-tension in capillary tubes. In order to obtain the highest values, he renewed the water-surface by a thread which absorbed the water on the surface.

Subsequent investigators, such as *Quincke*[1] (1858 and 1877), have observed that flat bubbles and drops of water and mercury have a very much greater surface-tension just after they have been formed than later. *Timberg*[2] (1887) has observed similar changes in the surface-tension of thin films of liquids. Quincke found that this progressive diminution of the surface-tension was less in small drops than in large ones, and he believes that this is the reason why a similar diminution is not generally observed in narrow capillary tubes; he found that the gradual decrease was reduced materially with the diameter of the tube.

Various explanations have been given to account for this progressive decrease of the surface-tension. A generally accepted explanation has been that by exposure to the air, a film of contamination would be formed on the water-surface, arising from the dust in the air, or from the water itself, etc.[3], partly also from a residuum left by evaporation of the water.[4]

An argument which originally weighed much with me against this theory, was derived from the fact that if, by contraction of a water-

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[1] Pogg. Ann. der Phys. und Chem., vol. CV, 1858, p. 35; vol. CLX, 1877, p. 569.

[2] Wied. Ann. der Phys. und Chem., vol. XXX, 1887, p. 545.

[3] See Marangoni, Nuovo Cimento, Ser. 2, vols. 5 & 6, 1872, p. 260; ibid, Ser. 3, vol. 3, 1878. Røntgen, Wied. Ann. der Phys. und Chem., vol. XLI, 1890, p. 329; vol. XLVI, 1892, p. 155. Lord Rayleigh, Proc. Roy. Soc. London, XLVIII, 1890, pp. 127—140. The last paper is of special importance for this question; see also Rayleigh's investigations on the reflection of light from liquid surfaces, Philosoph. Mag. vol. XXXIII, 1892, pp. 1—18.

[4] See Violle, 'Cours de Physique', Paris, 1884, vol. I, p. 660.

surface, I reduced its tension to a minimum and then left it undisturbed, I found, after some hours, that the tension had again increased, and continued to increase until it had reached a certain mean value, although the water-surface was exposed to the air the whole time (cf. p. 38). I thought that if the reduction of the surface-tension were due to a film of contamination, it was not probable that this contamination would again disappear to any great extent, even if it were concentrated by contraction.

Quincke believes (1877)[1] that the progressive decrease of the surface-tension must be due to a kind of elastic after-effect ("elastischer Nachwirkung") in liquids, similar to the so-called after-effect that we know in solids. He supposes that the molecules near the surface of liquids, like the molecules of solids, approach their position of elastic equilibrium only gradually and after some length of time.

In 1894[2], *Quincke* still seems to maintain the same view. He acknowledges, however, that changes in the surface-tension are due to impurities on the surface of the liquids, and remarks, in opposition to Hall[3], that the more the surface of a liquid is contaminated, the more uniform are the determinations of the surface-tension obtained; and that it is just the most skilful investigator who will find the greatest variations in the surface-tension. But at the same time, Quincke speaks of the elastic after-effect which would reduce the surface-tension about 6 to 10 per cent in pure water, and only in tubes with a diameter greater than 1 mm. — the wider the tube, the greater will be the effect. The value of the surface-tension, determined between parallel glass-plates or in flat air-bubbles, will only after 20 hours or more, approach the value which is obtained at once by determinations in narrow tubes. Other liquids, such as alcohol and mercury, show similar reductions of the surface-tension (5 to 10 %). In aqueous solutions of salts, even if they are very weak, the surface-tension is reduced 30 to 40 per cent or more.

In 1877, *Quincke* states that slight imperceptible impurities (solutions of salts, etc.) reduce tbe tension of a free surface considerably[4], and he adds: "Es scheinen sich bei längeren Stehen organische Substanzen zu bilden,

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[1] Pogg. Ann. der Phys. und Chem., vol. CLX, 1877, p. 568.
[2] Wied. Ann. der Phys. und Chem., vol. LII, 1894, pp. 4, 5.
[3] Phil. Mag., vol. XXXVI, 1892.
[4] Pogg. Ann. der Phys. und Chem., vol. CLX, 1877, p. 564.

welche die Capilarconstanten der frisch gebildeten Oberfläche zu klein erscheinen lassen". He says also that both in alcohol and water there are small changes in the surface-tension, and that he is not sure whether they arise from traces of another substance, or whether they show differences in the cohesion of the same liquid. He feels most inclined to assume the latter. A little later (l.c. p. 568) he states, however, that if he protects the meniscus or the free surface of the liquid in a tube from impurities, the height of the column may remain unaltered for hours.

Quincke has also observed (1870)[1] that the surface-tension on the boundary between two liquids is gradually reduced as time goes on. The surface-tension is greatest immediately after a drop of one liquid has been introduced into another, *e. g.* a drop of oil into water. This decrease, however, has been explained as being caused by a gradual mingling of the two liquids, although they do not apparently dissolve each other[2].

Quincke, however, also seems to be of the opinion that some apparent changes in the surface-tension may be owing to changes in the angle of contact, ϑ, which he maintains is only zero as long as the surface of the solid is absolutely clean; but this, he considers, can only be maintained for a short time, as the solid surface will gradually be coated with an immeasurably thin layer of other substances, adhering gases, whose thickness, however, is less than the radius of the sphere of molecular attraction[3]. The angle of contact between water and a clean surface of platinum would in this manner be increased from 0 to $10^0\ 43'$ after 2 minutes, and to $18^0\ 13'$ after 10 minutes, and so on. Quincke has moreover found[4] that the value of the surface-tension determined by capillary tubes, is lower than when determined on flat bubbles or drops, and he is of opinion that this also proves that the angle of contact, ϑ, cannot be 0^0, but, between water and a glass surface, must be $25^0\ 32'$ at a temperature of 20^0 C.

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[1] Pogg. Ann. der Phys. und Chem., vol. CXXXIX, 1870, p. 18.

[2] *Van der Mensbrugghe* (1887) has observed that a large drop of oil floating in an aqueous solution of alcohol, after some length of time acquired an irregular shape, owing to changes in the surface-tension produced by the formation of a distinct pellicle round the drop. Bull. de l'Acad. Roy. des Sciences de Belgique, Ser. 3, vol. XIII, 1887, p. 13.

[3] Wied. Ann. der Phys. und Chem., vol. II, 1877. p. 159; see also vol. XXVII, 1886, p. 219; vol. LII, 1894, p. 15; vol. LXI, 1897, p. 267.

[4] Pogg. Ann. der Phys. und Chem., vol. CXXXIX, 1870.

Wilhelmy[1] maintains that the reason why he found different values of the surface-tension of liquids by using various solids — glass giving lower values than brass and other metals — must be that ϑ is not zero, but is different for different solids.

We have seen that Quincke explains the differences and changes in the values of the surface-tension of the same liquid, as being caused partly by elastic after-effect, partly by contamination of the free surface or by traces of dissolved foreign substances, partly also by changes in the angle of contact, ϑ.

Volkmann[2] (1880, 1882, 1886) does not agree with Quincke on the last point. He maintains that if the angle of contact is not zero, this must be due to imperfect wetting of the surface of the solid, through its not having been clean; and this is a very important point. He states that it is not difficult to keep the surface of a solid (glass) pure, if it be only perfectly cleansed at the beginning, and is then thoroughly wetted with the liquid. He keeps his glass tubes in alcohol or water. He cannot, however, explain why Quincke obtains greater values of the surface-tension of liquids by measuring bubbles and drops, than by measuring the height of rising columns in tubes; and he feels inclined to believe that it may be owing to errors of observation. He also proves that the surface-tension of distilled water is only very slightly altered by the addition to its surface of slight impurities, *e. g.* salts, which are dissolved by the water[3]. This statement has also been confirmed by the observations of Röntgen (1886)[4].

Volkmann does not seem entirely disinclined to assume Quincke's explanation of the progressive decrease of the surface-tension as being an elastic after-effect, although he thinks that according to the idea we have hitherto formed of the after-effect, this should not occur in a substance with easily movable molecules, *i. e.* in ideal liquids. But if it exists, it is to be expected that it will be greater in more viscous liquids. It should, for instance, be greater in viscous solutions of salts than in pure water; and

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[1] Pogg. Ann. der Phys. und Chem., vols. CXIV, CXIX, 1863; CXXI, 1864; CXXII, 1864.

[2] Wied. Ann. der Phys. und Chem., vol. XI, 1880, p. 177; vol. XVII, 1882, p. 356; vol. XVIII, 1882, p. 135; vol. XXVIII, 1886, p. 136.

[3] See l. c. vol. XVII, pp. 364, 365, 389, 390.

[4] Wied. Ann. der Phys. und Chem., vol. XXIX, 1886, p. 207. Volkmann says, in 1894 (Wied. Ann. vol. LIII, p. 660), that Quincke's statement that small quantities of salt reduce the surface-tension, is easily explained by the fact that impurities are contained in the salt, and are thus added to the water.

this also agrees with the observations of both Quincke and Volkmann. During Volkmann's experiments with a very viscous solution of salts (K_2CO_3, $MgCl_2$, $CaCl_2$), it was almost impossible, for the space of some hours, to obtain a definite height of the column of liquid in a tube.

On the whole, Volkmann, in 1880 and 1882, is most inclined to believe that the progressive decrease in the surface-tension of liquids is owing to some influence of the air upon the free surface of the liquid. He does not, however, try to define the kind of influence that this might be. He found that this decrease was very much greater in exhausted water than in water that had been saturated with air (by shaking or by introducing a current of air-bubbles); and he believes the reason to be that the air has more effect upon exhausted water than in the latter case, where it is almost nil. For this reason he used for his determinations of the surface-tension, liquids which he had saturated with air in the above manner, as he could then more easily keep the heights of the rising columns in the tubes constant during a longer time. Whether the presence of air in a liquid actually changes its surface-tension, he could not, however, decide, but he thinks the change must at all events be insignificant, as the amount of air actually absorbed is so small. He also believes that very little can be judged from the first values of the surface-tension obtained by determinations in air-free water.

With regard to Quincke's observation that the wider the tube, the greater is the decrease in the surface-tension, Volkmann thinks that this is again due to the influence of the air, which has freer access to the surface of the liquid in wide than in narrow tubes. But Quincke's observation that the decrease was less in small drops and bubbles, than in larger ones, could not, at any rate, be explained in this manner.

In 1894, Volkmann to some extent changed his views. After careful investigation, he could not now find any difference between the changes of the surface-tension in exhausted water, and in water saturated with air, as long as he did not boil his glass tubes along with the water, in which case the glass is imperfectly wetted. He no longer believes that the influence of the air changes the surface-tension, but has arrived at the conclusion that these changes are due to undissolved impurities on the surface of the liquid[1]. He cannot, however, decide whether these im-

[1] Wied. Ann. der Phys. und Chem., vol. LIII, 1894, p. 654.

purities are derived from the air, or whether they are suspended in the liquid. He feels inclined to believe (l.c. p. 659) that the latter is the case, and that they "als kleine unlösliche Theile suspendirt sind, und vom Inneren aus die Oberfläche bedecken". This would also be the reason why capillary tubes with diameters of less than 1 mm. exhibit such constant surface-tension of the liquid, as according to Liebreich's observations on capillary "dead space"[1], particles with little buoyancy find the limit of their rise already at a perceptible distance from narrow capillary surfaces, while they can rise more easily in flat bubbles, which have so much larger a surface.

Quincke's experience that solutions of salts exhibit such a great progressive decrease in the surface-tension (30 to 40 %) may also, according to Volkmann, be explained in a similar manner, as the dissolved salts produce so many impurities, which are suspended as small particles in the water. He also seems to think that impurities that are not dissolved, reduce the wetting property of the liquid (l.c. p. 661).

The only circumstance which Volkmann thinks might contradict his views is that Quincke has found such high values of the surface-tension in flat bubbles of water and aqueous solutions; but he feels satisfied that the discussion on the subject of late years seems to throw doubt on these values.

To me it seemed at first as if none of the above explanations were fully satisfactory or able to explain all the phenomena.

The theory of an elastic after-effect in liquids I do not consider tenable for several reasons, the most decisive of which is that if the surface-tension of water, or sea-water, be reduced to its minimum, and the surface be then left standing undisturbed for some time, the surface-tension will again increase until it acquires a mean value (see pp. 38, 43). If the gradual decrease, in course of time, of the tension of a fresh surface is caused by the gradual approach of the water molecules — or the water and salt molecules — to their position of elastic equilibrium, I do not see how they can reverse their movement, after the surface-tension has been once brought to a minimum[2].

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[1] Sitzungsber. der Berliner Akademie, 1890, p. 1239.

[2] Another fact which makes this explanation improbable is that while mercury, water, and aqueous solutions change their surface-tension considerably, it is not possible to produce any changes in the surface-tension of other liquids, such as alcohol, carbon bisulphide, etc. See later.

That the angle of contact, ϑ, might increase in course of time, owing to defective wetting of the surface of the solids, I considered probable, and believed that this might be the cause of many apparent changes in the surface-tension; but it could not, of course, explain the changes caused by immersing bodies in, or withdrawing them from, the water.

It is, in my opinion, clear that on the free surface of water or aqueous solutions, there is gradually formed an immeasurably thin coating or film, composed of matter, the surface-tension of which is less than that of the mass of the liquid. If the exposed surface be extended, this film is attenuated and the surface-tension is increased towards a maximum, which is the real tension of the liquid; if the surface be contracted the film thickens, and the tension is reduced towards a minimum, which is the tension of the matter forming the film.

This supposition explains most easily the various phenomena mentioned above. If a new water-surface be formed — *e. g.* on a glass rod, by dipping it in water — a film of this description, with lower tension, will at once begin to develope on this surface, at first very thin, but gradually becoming more perceptible. If now a wet glass rod be slowly immersed in water in a vessel, this film will come into contact with the water-particles just below the surface; but having less tension, it must spread on the top of this part of the water[1], and the result will be that the very extreme layer is gradually skimmed off from the water covering the glass rod, as this passes down, and spread over the surface of the water in the vessel. In this manner the surface-film is gradually more and more concentrated within a smaller area, and this must lower the surface-tension towards a minimum.

If on the other hand, an immersed glass rod be slowly lifted, the circumstances will be reversed. The glass rod is now covered with a layer of water from the interior of the liquid, which naturally has a higher tension than the surface-film, which will therefore stream towards, and cover the wet surface of the rod, as soon as this passes upwards through the water-surface. Thus the latter is extended, the surface-film is attenuated, and this must increase the tension towards a maximum.

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[1] Cf. p. 37.

The above supposition will also, I think, explain the observation of several investigators (cf. Quincke and Volkmann), that the progressive decrease of the surface-tension of water and aqueous solutions is generally less appreciable in capillary tubes, than between parallel glass plates, in bubbles and drops, and in extended films. If the wet method, specially recommended by Volkmann, be used, the inner wall of the capillary tube is covered with a film of the liquid, which may have been recently formed, but which will nevertheless lower the surface-tension somewhat, if only a trifle, by contraction, which must occur to a very great extent, when the column of the liquid rises in the tube to find its equilibrium, as the exposed film is then accumulated within the small area of the free surface of this column[1].

The narrower the tube, the greater must be the reduction of the surface-tension, for the greater is the area of the film on the inner wall of the tube compared with the area of the free surface of the liquid column[2]. It is, however, obvious that the more the surface-tension is lowered beforehand, the less must be its subsequent diminution. Thus the progressive decrease of the surface-tension might be expected to be less in capillary tubes than in flat bubbles and drops, etc., and also less in narrow tubes than in wider ones, which is precisely what Quincke has found (see above p. 42)[3].

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[1] If the tube be lifted a little after the column of liquid has reached its full height, some part of the surface-film is again carried away on the inner wall of the tube, but it will not generally be sufficient to counterbalance previous concentration of the surface-film.

[2] This explanation may not seem to cover observations made with Quincke's so-called dry method, by which the column of liquid rises in a dry tube. But I believe that in that case, either the inner wall of the tube will not be perfectly wetted, and the angle of contact will be >0, as Quincke has generally found it, or, in order to secure a perfect wetting, the tube may be moved a little up and down, and we have the conditions for a concentration of the surface-film. Besides this, it must be remembered how extremely difficult it is to produce an absolutely clean surface, and the slightest traces of impurity of any kind on the inner wall of the tube, will of course be accumulated on the free surface of the liquid column, as it rises in the tube.

[3] That the progressive decrease of the surface-tension is less in small drops and bubbles than in larger ones, as found by Quincke, seems easy to explain. As will be proved later (see Concluding Remarks at the end of this chapter) the progressive contamination of the liquid surfaces is generally derived from the solid surfaces with which the liquids come into contact; but it is then evident that the larger the surface of the drop or bubble, the longer will be the time that must elapse before the contamination from the glass surface is fully extended over it. It should also be remembered that while a drop or bubble of water is being formed, its original surface is more and more extended, and that therefore the larger the drop or bubble becomes, the more must

But if this be correct, we must expect the values of the surface-tension of liquids obtained by determinations in capillary tubes to be below the maximum, and lower than those obtained otherwise, *e. g.* by measuring flat drops and air bubbles, etc. This also agrees well with what has been found by Quincke and others[1].

Sondhaus's method[2], with a ring of adhesion, might be expected to give high values of the surface-tension, as here, by the lifting of the ring, the film, whose surface-tension is measured, is to some extent formed during the observation, and we may thus obtain the value of tension of a freshly exposed surface. The values obtained by this method are also, as a rule, higher than those obtained in capillary tubes[3].

Lord Kelvin's[4] and Prof. Tait's method of measuring ripples might be expected to give high values of the surface-tension of water, as it is easy to produce a comparatively clean liquid surface for this kind of observation; and then the surface is observed while it is in motion, and its tension is apt to be increased; cf. my observation, mentioned on p. 21, that by putting the water-surface in motion, the indications of the hydrometer are reduced. The values of the surface-tension found by Kelvin's method are also on the whole higher than those found in capillary tubes[5].

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its surface-tension be increased; but then the subsequent decrease of the surface-tension must also be greater.

[1] Quincke's explanation that the difference in the values of the surface-tension is due to the angle of contact, which is generally > 0 in capillary tubes, may be correct, especially when his dry method is used, as the tubes may than be imperfectly wetted inside. With Volkmann's wet method, by which the tubes are carefully wetted, this seems perhaps less probable; but here the surface-tension is reduced by accumulation of exposed surface-film on the free surface of the rising column of liquid. And this is evidently the reason why the values of the surface-tension determined by this method often have a tendency to be lower than those obtained by the dry method of Quincke. See Quincke, Wied. Ann. der Phys. und Chem. vol. LII, 1894, p. 1; vol. LXI, 1897, p. 268. Volkmann, ibid. vol. LIII, 1894, pp. 633, 664; vol. LVI, 1895, p. 457; vol. LXII, 1897, p. 507; vol. LXVI, 1898, p. 194.

In one of his previous papers (see above, p. 46), Volkmann expressly states that he takes no notice of the first higher values of the surface-tension of air-free water in capillary tubes, as they are immediately reduced.

[2] Pogg. Ann. der Phys. und Chem. Ergänzungsband VIII, p. 266.

[3] See Timberg, Wied. Ann. der Phys. und Chem. vol. XXX, 1887, p. 545. Weinberg, Ostwalds Zeitschrift, vol. X, 1892, p. 50.

[4] W. Thomson, Philosoph. Mag. 4th series, vol. XLII, p. 368.

[5] See L. Matthiesen, Pogg. Ann. der Phys. und Chem., vol. CXXXIV, p. 107; vol. CXLI., p. 385; Wied. Ann der Phys. und Chem. vol. XXXVIII, 1889, p. 118. Kolaček, ibid. vol. V, p. 429. Lord Rayleigh, Philosoph. Mag., 5th series, vol. XXX, 1890, p. 386. Riess, Repertorium der Physik von Exner, vol. XXVI, 1890, p. 122. Ochsé, ibid. p. 646.

But of what nature is the matter forming the film which reduces the surface-tension? I thought at first that by exposure to the air, an immeasurably, thin film of condensed gases was formed on the surface of liquids, similar to that which is formed on the surface of solids. This film might have a much lower tension than the mass of the liquid. A condensation of gas molecules between the molecules of the surface of a liquid must, I thought, reduce the cohesion between the latter[1]. It might be in some such way as Volkmann's finding the cohesion of an aqueous solution of a salt to be intermediate between the cohesion of the water and that of the molecules of the salt[2].

Kundt's determinations[3] of the surface-tension of liquids exposed to gases compressed under high pressures, prove that the gases actually reduce the surface-tension of the liquids, but the reduction is very slight, and would be insignificant under ordinary pressure. This fact seemed to disprove the correctness of the above suggestion, but I thought it might only apply to the gases absorbed in the mass of the liquid, while it might be different with the supposed film of condensed gases on its free surface. I was confirmed in my belief by the observation that samples of sea-water have often a lower surface-tension when they have just been taken and are supersaturated with air, than they have later (see pp. 13—20); and this also seemed to agree well with Volkmann's observations of 1880 and 1882 on air-free water, and water that had been saturated with air (see above, p. 46).

The old experiment of Donny (1846)[4] also seemed to indicate that the presence of air in the water actually diminishes its cohesion. He had two closed glass-tubes half filled with water, one tube being exhausted, while the other was filled with air under ordinary pressure. If he placed the two tubes vertically with the ends filled with water upwards, and tapped them at the top, the water column in the tube filled with air would at once, at the

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[1] The phenomenon would to some extent be analogous to the gradual diminution of the surface-tension on the boundary surface between two liquids (see p. 44). This might seem to prove that there is a gradual absorption of the molecules of the one liquid between the molecules of the surface of the other liquid, *e. g.* oil and water.

[2] Wied. Ann. der Phys. und Chem., vol. XVII, 1882, p. 382.

[3] Wied. Ann. der Phys. und Chem., vol. XII, 1887, p. 538.

[4] F. Donny, Bruxelles Mémoires Couronn. vol. XVII, 1843—1844; Ann. de Chimie, vol. XVI, 1846, p. 167; Bibl. Univ. Archives, vol. I, 1846, p. 188; Pogg. Ann. der Phys. und Chem. vol. LXVII, 1846, p. 562.

gentlest tap, break off and slip down to the other end, while with the most violent knocks he was unable to make the water-column in the exhausted tube leave the upper end.

I thought that the above suggestion would also explain the observation that a surface-tension which was lowered to a minimum by contraction of the surface, begins after a while to increase again, until it reaches a mean value (see p. 43). If the film with condensed air be made thicker by contraction, it will be supersaturated with air, and if it be left alone for some time, the superfluous air will gradually be given off, until the surface reaches its natural degree of saturation.

It has been found that the surface-tension of liquids measured in capillary tubes decreases less rapidly with rising temperature than in bubbles and drops, and the values of surface-tension obtained by Sondhaus's method, with a ring of adhesion, and by the method of ripples, decrease most rapidly. I thought the explanation might be that most liquids condense more air on their surface at lower than at higher temperatures, and the difference between the maximal and minimal value of the surface-tension should, therefore, be greatest at the lower temperatures, while at temperatures where the liquids condense or absorb very little air (*e. g.* boiling-point of water), there should hardly be any difference between the maximum and minimum value. We must therefore expect that the farther the originally observed surface-tension is below its maximum value, the less can it decrease with rising temperature.

If we suppose that the difference between the maximum and minimum values of the surface-tension of a liquid at a certain temperature is proportional to the quantity of air that the liquid can absorb at the same temperature[1], and if g_o be this quantity at zero Centigrade, and g_t the quantity at another temperature t, we may to some extent expect

$$\frac{g_o}{g_t} = \frac{\Delta_o}{\Delta_t}$$

where Δ_o is the difference between the values of the surface-tension found by two different methods at zero Centigrade, and Δ_t the same difference at the temperature t. Knowing g_o and g_t, we can now examine whether this is approximately correct.

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[1] I assume that the quantity of gas condensed on the surface of a liquid is proportional to the quantity that the mass of the liquid can absorb.

According to Bunsen's determinations, water should be able to absorb, at 0° C., a quantity of air equal to 0·0247 of its own volume, and at 16° C. 0·01895 of its volume. We then have, when $t = 16$,

$$\frac{g_o}{g_t} = \frac{0{\cdot}0247}{0{\cdot}01895} = 1{\cdot}31.$$

As an example for comparison we will take the values of the surface-tension, α $^{mg.}/_{mm.}$, found at 0° C. and 16° C. by *Sondhaus* by observations in capillary tubes, which are $\alpha'_0 = 7{\cdot}69$ and $\alpha'_{16} = 7{\cdot}44$, and the corresponding values found by *Timberg* at the same temperatures by observations of extended films (by Sondhaus's ring of adhesion), which are $\alpha_0 = 8{\cdot}24$ and $\alpha_{16} = 7{\cdot}87$. We suppose the latter values to be nearly maxima of α. We then find:

$$\frac{\Delta_0}{\Delta_{16}} = \frac{0{\cdot}55}{0{\cdot}43} = 1{\cdot}28$$

which may be said to agree well with the value found above for $\frac{g_o}{g_t}$ considering that these results have been obtained by a very rough calculation, and that the values of α $^{mg.}/_{mm.}$ are taken somewhat at random.

But if the above supposition were right, one would expect that there would be less difference between the temperature-coefficients of the tension found by the various methods for liquids whose absorption of air is less dependent on the temperature, *e. g.* alcohol. Timberg has found a larger temperature-coefficient of alcohol by the bubble method than by Sondhaus's, although the former gives a much lower value of α; this is too much the other way, and seems somewhat astonishing. It is, however, in striking accordance with the above supposition, that the difference between the values of α found by the two methods, is very much larger for alcohol than it is for water, since alcohol absorbs on the whole a good deal more air than water does.

The difference between the values of α $^{mg.}/_{mm.}$ at 0° C. for alcohol, found by Timberg by the two methods, is about 0·2107, while the difference between his values of α at 0° C. for water, determined by the same methods, is about 0·033

$$\frac{\Delta_{0\,\text{alc.}}}{\Delta_{0\,\text{water}}} = \frac{0{\cdot}212}{0{\cdot}033} = 6{\cdot}4.$$

At 0° C., according to Bunsen's determinations, alcohol will absorb a quantity of air equal to 0·160576 of its own volume, and water will absorb 0·0247 of its own volume. The quantity of air absorbed by alcohol at 0° C. is consequently

$$\frac{0{\cdot}16058}{0{\cdot}0247} = 6{\cdot}5$$

times larger than that absorbed by water at 0° C. If the supposition be correct, the difference between the values found for the surface-tension, α $^{\text{mg.}}/_{\text{mm.}}$, by the two methods should consequently be 6·5 times greater for alcohol at 0° C. than it is for water. In the case chosen above, we have found that it is 6·4 times greater, which must be said to agree remarkably well.

On the whole, the above considerations might seem to confirm in a convincing manner the correctness of the suggestion that the changes in the surface-tension of liquids is caused by condensation of air on their surface[1]. But if this be the case, one would expect that water heated to nearly its boiling point would exhibit very slight changes in its surface-tension, as it then absorbs so little air.

I used for the experiment the ordinary tap-water of Christiania, which is very pure, and the changes in the surface-tension were observed by a hydrometer of metal, to the stem of which I had fixed a thin plate of mica. Cold water was poured into a beaker of hard Jena glass, the hydrometer was immersed and loaded so that the centre of the mica plate came on the water-line. By immersing and removing strips of dry, clean writing-paper, the hydrometer could now be made to sink nearly 2 cm. By again immersing the wet pieces of paper, it was made to rise more than 2 cm.

The water was now boiled, and all air driven out. When the water had a temperature between 80° C. and 90° C., the hydrometer was again immersed and properly loaded. Many pieces of dry, clean paper were now immersed,

[1] Quincke's observation (Pogg. Ann. vol. CXXXV, 1868) that the height of the meniscus of water on the inner wall of an exhausted glass bottle is reduced from 4·135 to 3·867 by standing for some weeks, might seem to disprove the correctness of this suggestion. I considered it, however, probable that Quincke's explanation was correct, and that the angle of contact had been increased, owing to imperfect wetting of the glass. If so, the change was not due to any diminution of the surface-tension. On the other hand, the influence of air was not entirely excluded; for although the bottle had been exhausted, the surface of the glass certainly contained gases which have only gradually been given off. I did not therefore consider this experiment decisive.

but the hydrometer remained undisturbed in the same position. All the pieces of paper were again drawn up through the surface, and removed one by one, but the hydrometer did not move either up or down. This experiment was repeated several times, and with the same result. I wetted pieces of paper with ordinary cold water, and immersed them in the warm water; a rise of the hydrometer was now perceptible, but quite insignificant. The temperature of the water had then sunk to about 72° C.

This seemed to confirm our theory beautifully.

I tried the hydrometer again in ordinary cold water, which had been standing at rest in a glass beaker for several hours. But even there I could now only produce slight and irregular changes in the position of the hydrometer by immersing and removing dry or wet pieces of paper. I received the impression that after the exposure to the hot water, the surface of the stem and the mica was imperfectly and irregularly wetted, probably in the same way as Volkmann's glass tubes lost much of their wetting property after having been boiled for some time[1]. Two days later, I tried the hydrometer with the mica-plate again in the same boiled water, which had been standing at rest in the same beaker covered with a glass plate. It was still very difficult to produce any appreciable changes in the position of the floating hydrometer by immersing or removing pieces of dry or wet paper. It was afterwards ascertained that the water still contained but little air, as no air-bubbles were formed in it by heating.

These experiments did not seem to confirm my supposition that it was the air which produced the changes in the surface-tension. I came however to the conclusion that the surface of the water had perhaps been too much contaminated by the boiling to be purified by immersion of paper; evidently also it did not wet the mica-plate properly. The reason why Hagen got a very much lower surface-tension of the water after it had been boiled[2], has probably been a similar one.

Assisted by Mr. O. Castberg, I made the following experiments. An oblong trough of glass or tin with parallel walls was used. In this vessel

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[1] Wied. Ann., vol. LIII, 1894, p. 646. The explanation is probably that the soluble parts of the surfaces of the glass and the mica are dissolved by the hot water, and the surfaces afford less adhesion to water afterwards.

[2] Pog. Ann., vol. LXVII, 1846, p. 159.

there was a partition-wall (Fig. 1, *a*) of Mr. Castberg's construction made of thin sheet-brass which fitted closely to the parallel walls on both sides without reaching the bottom of the vessel, but which could slide along these walls, so that the partition could easily be moved from one end of the trough to the other. If the vessel were filled with water, this partition-wall would divide its surface into two parts, and by moving the wall backwards or forwards, one part of the water-surface was extended while the other part was contracted. A plate of very thin platinum or mica (Fig. 1, *b*) was carefully cleaned in a strong solution of potash or soda, so that it was perfectly wetted by water. The plate suspended under a balance was immersed in the water at one end of the trough, and the balance was brought to its equilibrium. If the partition-wall were now moved towards that end of the trough in which the plate was immersed, the latter would rise at once several centimetres, and would perhaps be raised out of the water; if, however, the partition-wall were moved in the opposite direction, the plate would sink several centimetres, the reason being that in the former case the exposed free water-surface is contracted, and its tension is consequently lowered towards a minimum, while in the latter case the water-surface is extended, and the tension increased towards a maximum. We thus had here a very practical arrangement by which the surface-tension of the water could easily and quickly be increased to maximum or reduced to minimum at will.

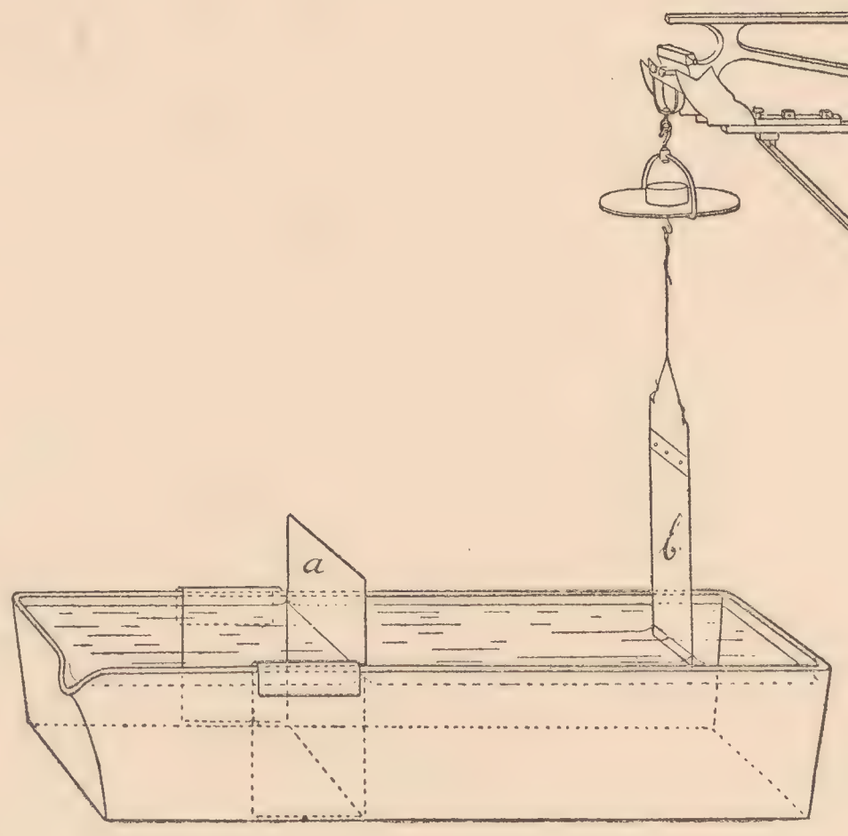

Fig. 1.

In this manner I now examined the changes in the surface-tension in ordinary water, in water which had been exhausted by boiling, and in water exhausted by an air-pump, but I could not find any certain or appreciable difference between them. The surface-tension seemed to change about the same, under similar circumstances, whether the water was exhausted or not. During one experiment, the water exhausted by boiling showed greater differ-

ences between maximum and minimum of the surface-tension, than ordinary tap-water, while water exhausted by the air-pump seemed to exhibit very much the same differences as freshly-drawn tap-water. It seemed, however, as if the water-surface had been somewhat contaminated by the boiling; for during other experiments, the boiled water showed almost exactly the same changes of the surface-tension as ordinary water, nor could I find that the maximal surface-tension of exhausted boiled water was any greater than that of ordinary water at the same temperature.

The following rough determinations of the surface-tension, α, were made:

	Maximum value of α mg./mm.	Minimum value of α mg./mm.	Difference.
Tap-water, freshly drawn; $t = 11^0$ C.	7·3	4·4	2·9
Tap-water, heated to 16° C., and supersaturated with air.	7·1	4·4	2·7
Exhausted boiled water at 13·8° C.	7·3	4·2	3·1
Exhausted boiled water at 22° C.	6·9	4·0	2·9

As is here seen, the values of α are not higher in exhausted water than in ordinary tap-water, and the differences between the maximal and minimal values of α are almost identical, the discordances being within the limits of the errors of observation, as the determinations were very roughly made.

The diminution of the surface-tension of ordinary water, as we see in these experiments, is about 40 per cent, which is much the same as Quincke found for aqueous solutions of salts, while he states that it should be only 5 to 10 % in ordinary distilled water. There is no appreciable difference in this respect between distilled water, and the ordinary tap-water of Christiania, used by us, which is very pure. The great difference with regard to the progressive diminution of the surface-tension, found by Quincke between distilled water and solutions of salts seems to be of an accidental nature.

These experiments seemed to disprove the theory that the changes of α were due to absorbed air; as we should then have expected that the changes would have been very much greater in exhausted water. They seemed to me to indicate that the changes might be due to contamination of the water-surface.

This belief was confirmed by the following experiment. I skimmed the surface of the water carefully, by placing the partition-wall as near as possible to that end of the trough in which the suspended plate was immersed, and then moving it to the other end of the vessel, where it was lifted and quickly placed near the first end again, in order to be carried towards the other end once more. This operation was repeated several times, in order that all contamination might be skimmed to this end of the vessel, and by the movable partition-wall prevented from again coming into the other division in which the suspended plate was immersed. If the changes of the surface-tension were actually caused by a concentration or an attenuation of a film, contaminated by some foreign matter, the tension of this skimmed surface should not be changed by contraction or expansion. This proved to be actually the case; even by moving the partition-wall close up to the immersed plate, I could not make it rise; and when the partition-wall was again moved back, the plate still remained in precisely the same position; it had suddenly, as it were, become insensitive to the changes in the area of the water-surface. After this clean water-surface had, however, been free for some time, the plate could again be made to rise or sink a little by moving the partition-wall[1].

But even this experiment did not seem quite decisive, for a film of condensed air would also be carried away by skimming the surface, and by

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[1] This experiment is in some respects quite similar to Lord Rayleigh's experiments on the "superficial viscosity of water" with a compass-needle oscillating on contaminated and clean water-surfaces. (Proc. Royal Soc. London, vol. XLVIII, 1890, p. 127). I believe, however, that his method of cleansing the water-surface by a stream of wind and convection currents (see l. c. pp. 133, 134) is more complicated and less effective than the method described above. As Lord Rayleigh has pointed out (l. c. pp. 134, 135) a very delicate test whether the water-surface is clean or not, is afforded by its behaviour towards the advancing or retreating edge of the needle, or, in the above case, of the partition-wall. By watching motes, it may be observed that when the surface is not absolutely purified by skimming, it will be moved as a more or less viscous film or pellicle before or after the advancing partition-wall. The reason is that the surface-film is contracted before the advancing wall, and the tension is lowered; this part of the surface will therefore at once spread over the nearest surface in front which has a higher tension, and thus the movement may be transferred to the whole surface. Behind the wall, it will be *vice versa*. If the water-surface be absolutely clean, a contraction will produce no effect upon the surface-tension, the surface will not move before the advancing wall, and the motes lie quiescent until struck. This is in my experience the simplest and at the same time a very delicate manner of testing the state of a water-surface; a small clean platinum-plate, previously ignited, may conveniently be used for the purpose.

exposure to the air the water-surface might possibly be coated by a new film of condensed air.

I tried the effect of various kinds of dust or powders on a carefully skimmed water-surface in which no changes of the surface-tension could be produced by contraction, and I found that the ordinary dust of an inhabited room scattered on the clean water-surface, reduced the surface tension, and made it quite as changeable as before the surface had been cleansed. Powder of filed cork had a similar effect[1]. This seemed to prove that dust is at least one cause of the marked changes in the surface-tension of water. But will all kinds of dust act, or is the effect owing to greasy matter contained in the dust?

I tried powder of charcoal which had been glowing, but by spreading this on the skimmed water-surface, the tension was not diminished, and remained quite as unchangeable during contraction or extension of the surface as it had been. The ash of a cigar had the same effect. But if the heated powder were rubbed a little between the fingers before it was scattered on the water-surface, it would reduce the tension as ordinary dust did.

These facts tend to the conclusion that it actually is greasy matter in the dust which diminishes the surface-tension.

A convenient manner of examining whether dust or powder falling on the surface of a liquid changes its surface-tension or not, is simply to notice how the powder behaves when it touches the surface. If it then spread rapidly to all sides, it diminishes the surface-tension considerably; it spreads because the thin film of liquid whose tension it diminishes, will immediately spread over the surface of the rest of the liquid, where the tension is greater. But if the dust increase the surface-tension by absorption, it will naturally contract at the moment it touches the surface of the liquid. If the dust remain quietly where it touches the liquid, it has very little effect upon the surface-tension[2].

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[1] This is not, however, always the case, at least not to the same extent. It evidently depends upon whether the cork contains more or less greasy matter.

[2] It should be remembered, that if the dust have no effect upon the tension of the liquid surface, the particles of dust should be drawn together by the menisci of the same shape formed round each particle. But if some particles be wetted by the liquid, and form concave menisci, while others are not wetted and form convex ones, they should repel each other; the movements caused in this manner are, however slight.

If, under ordinary circumstances, it be the dust which causes the changes in the surface-tension, it might be expected that in very dirty water, where great quantities of dust were suspended, the surface would always be so contaminated that its tension could not be increased much above a minimum.

I collected quantities of ordinary dust from a room, and mixed it in the water of my trough, so that this looked quite muddy. The surface-tension was naturally at once reduced to near its minimum, but nevertheless showed the same changes by extension or contraction of the surface in this dirty water as in ordinary water; and when the surface was skimmed, its tension reached a maximum and remained nearly as unchangeable as in ordinary clean water.

None of the experiments could be said to prove decisively that the air was of no importance for the progressive diminution of the surface-tension of liquids. Quincke had found[1] that carbon bisulphide was the only liquid, in which he did not obtain a lower value of the surface-tension by the method of capillary tubes than by the method of flat bubbles. By the first method he found $\alpha = 3{\cdot}343$, and by the latter $\alpha = 3{\cdot}274$. I thought the explanation might be, that this liquid condenses very little air on its surface at ordinary temperatures, as it is then near its boiling-point.

By making experiments with carbon bisulphide in the same manner as above described for water, I found that the surface-tension of this liquid was absolutely unchanged, when it was skimmed; the immersed plate remained undisturbed in the same position the whole time. I tried dust of various kinds on the surface, but in no way was I able to change the surface-tension in the least.

I now tried alcohol. If the absorption or condensation of air actually has an appreciable effect upon the surface-tension, it may be expected to be considerable in this liquid which absorbs so much more air than water does (cf. above, p. 53). But as might have been expected from Plateau's[2], Marangoni's and Lord Rayleigh's experiments, I found that alcohol behaved in this respect exactly like carbon bisulphide. It was absolutely impossible to produce the slightest change in any way in its surface-tension, even by dust or oil.

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[1] Pogg. Ann. der Phys. und Chem. vol. CXXXIX, 1870.

[2] Mémoires de l'Acad. de Belgique, vol. XXXVII, 1868, p. 1; Pogg. Ann. der Phys. und Chem., vol. CXLI, 1870, p. 44.

This was in my opinion a decisive proof that the demonstrated changes in the surface-tension of water and aqueous solutions are not caused by absorption or condensation of air on their surfaces[1]. I was convinced that these changes are produced by *contamination of the surface with foreign substances* — probably greasy matter, as assumed by previous observers — *which have a higher surface-tension than alcohol and carbon bisulphide, and which cannot therefore spread over, and contaminate, their surfaces.* The above experiments also prove clearly that if the contaminating substance is composed of really solid matter, dust or powder, which contains no liquid or viscous substances that can spread on the top of the liquid, and form a continuous film, it has no effect upon the surface-tension; for otherwise dust floating on the surfaces of alcohol and carbon bisulphide would change their tension.

In later experiments, I have somewhat improved the method described on p. 56 for determining the changes in the surface-tension of liquids, by using for immersion a thin platinum plate whose surface is covered with platinum-black, and which is heated to redness before use. The surface of this plate is easily uniformly and completely wetted, and it is moved with astonishingly little friction up and down through the liquid surface[2], so that although the plate has a breadth of 26·6 mm., changes in the weight of its meniscus of less than half a milligram can be measured. This plate is carefully cleansed by a solution of ammonia or caustic soda, and is well rinsed in pure water. The upper part of the plate is kept dry, after it has been heated, while the lower end is wetted with the liquid to be examined, to about 8 or 10 mm. above the lower edge, and is suspended under the balance, and weighed after all superfluous liquid has been removed. The trough containing the liquid is now placed under the suspended plate so that the lower edge of the latter just touches the surface of the liquid when the balance is level. By now weighing the tension with which the plate is drawn downward, the surface-tension, α $^{mg.}/_{mm.}$, of the liquid can be very accurately

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[1] A still better proof is afforded by the experiment mentioned later, where a clean free water-surface is kept for days exposed to the air in a previously heated platinum cup without exhibiting the slightest indication of diminution of its tension.

[2] Cf. Kohlrausch's observations with a platinum suspension-wire covered with platinum-black for hydrostatic weighing. (Wied. Ann. der Phys. und Chem., vol. LVI, p. 187).

determined. Constant care has only to be taken to keep the plate wet up to the original distance of 8 or 10 mm. above the lower edge.

If the changes in the surface-tension of water and aqueous solutions were caused by very small quantities of greasy matter suspended in an extremely fine state of subdivision in all kinds of water, I thought it might be interesting to examine whether there were similar changes in aqueous solutions of substances which destroy grease and oil readily, converting them into soluble soaps; for it might seem probable that the changes there could not be so great. I tried with strong solutions of caustic soda and ammonia.

The solution of caustic soda was about 30 % strong. A rectangular trough similar to that described on pp. 55, 56, was filled with this solution, the temperature of which was 13·6° C. The platinum plate, described above, was suspended under the balance, and immersed as before. The lower edge of the plate was 26·6 mm. broad. The surface of the liquid was carefully cleansed by skimming as described on p. 58, and the weight of the meniscus round the plate was 450 mg., which gives a surface-tension of 8·46. By contracting the surface-film of the liquid repeatedly round the suspended plate (see p. 56) the weight of the meniscus was reduced to 150 mg. as a minimum, which gives a surface-tension of 2·82. This is a reduction of the surface-tension of about 66 %.

In a strong solution of ammonia, I found in the same way the maximum value of the surface-tension to be 6·0 and the minimum value to be 3·0. By adding a small drop of olive oil to the skimmed surface, its tension was at once reduced to its minimal value of 3·0.

It will be seen that these aqueous solutions have even considerably greater changes in their surface-tension than pure water, in spite of their ability to convert greasy matter into soluble soap. It seems as if in this respect they resemble regular solutions of soap and oleate of soda, etc., in which the changes of the surface-tension may be considerable, and which have a still lower minimum value of surface-tension[1].

By the apparatus described (p. 56), I now examined whether there was much difference in this respect between ordinary, pure, fresh water and sea-water.

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[1] Lord Rayleigh has found the minimum surface-tension of a water-surface saturated with oleate of soda to be about 2·5. (Philosoph. Mag., vol. XXX, 1890, p. 398).

In tap-water, freshly drawn, I determined the maximum value of the surface-tension, at 8° C., to be 7·57. By contraction, the tension of the recently formed, but not skimmed, water-surface was reduced to 5·55. By the contraction of a similar water-surface, after it had been free for many hours, the surface-tension was reduced to 3·76; the temperature of the water being 12° C. By dipping the fingers in a clean water-surface, the tension was reduced to 4·7. By adding a drop of olive oil to a clean surface, the tension was reduced to 4·51.

In sea-water with a specific gravity $\left(S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}\right)$ of 1·02650, and a temperature of 12° C., I found the maximum value of the tension of a carefully skimmed surface to be . . . . . 7·67.

By contraction of a recently formed, but not skimmed, surface, the value was reduced to . . . . . 4·98.

By contraction of a surface which had been free for some time, the value was reduced to . . . . . 4·32.

By adding a drop of olive oil to a pure surface, the tension was reduced to . . . . . 3·76.

I had observed before that immersed filter-paper had probably a reducing effect upon the surface-tension of water (see p. 33). By careful investigations with this apparatus, I found this confirmed; and I found, moreover, that the various kinds of filter-paper have not all the same effect.

In the same sea-water as above, I increased the surface-tension, by skimming, to . . . . . 7·56.

A round piece (diameter = 11 cm.) of dry filter-paper, cleaned with hydro-chloric acid and fluoric acid, when immersed, reduced the tension to . . . . . 4·51.

Another piece of the same kind immersed, gave a tension of . . 4·32.

A third piece of the same kind immersed, gave a tension of. . . 3·95.

By removing the three pieces of paper, one after another, the tension was again increased to . . . . . 7·33.

And by skimming the surface, the tension was increased to . . . 7·56.

The experiment was repeated several times, but always with the same result; by the immersion of several pieces of this kind of cleaned filter-paper,

the surface-tension was always reduced to 3·95, whether the surface-tension was previously increased to maximum, or reduced to minimum.

By immersing pieces of filter-paper which had been treated with sulphuric acid (the so-called "gehärtete Filter"), the surface-tension of the same sea-water was repeatedly reduced to 6·0, but could not be reduced lower. On the removal of this filter-paper, the tension would again rise to 7·33. If, by contracting the surface, the tension was reduced to 5·0, the immersion of a piece of this kind of filter-paper would increase the surface-tension to 6·0 or even more.

By immersing pieces of ordinary filter-paper which had not been specially cleaned, the surface-tension could be reduced to 5·64.

The effect of immersing pieces of filter-paper was very much the same in ordinary, pure, fresh water as in sea-water.

By immersing pieces of ordinary, clean writing-paper, the surface-tension of sea-water or fresh water was always increased to a maximum. Even pieces of an ordinary newspaper had a similar effect.

It seemed to me puzzling why filter-paper had such a reducing effect upon the surface-tension of water. I thought that it was due to minute traces of greasy matter adhering to the fibres of the paper, and with which the water-surface might be contaminated. I therefore had some filter-paper carefully treated for hours with distilled ether to free it from all traces of grease. This filter-paper was carefully dried, and touched only with forceps and scissors which had been heated over a smokeless Bunsen gas-flame; but it nevertheless had exactly the same effect upon the surface-tension. Four pieces of this cleaned filter-paper immersed, reduced the surface-tension of sea-water from 7·52 to 4·23, while the immersion of three pieces of filter-paper, which had not been cleaned, reduced the same tension to very nearly the same value. The removal of the pieces of filter-paper increased the surface-tension again to 7·36.

In order to examine whether the ether by evaporation might leave some residuum which has a reducing effect upon the surface-tension, I let drops of ether evaporate on the surface of a platinum plate which had been carefully cleaned and heated to redness over a Bunsen flame. By immersing this plate in water whose surface-tension had been increased to a maximum, I could not, however, produce the slightest reduction in the tension. I more-

over soaked several pieces of ordinary writing-paper in ether, which was afterwards evaporated; but neither had the immersion of these pieces of paper any appreciable reducing effect upon the surface-tension. It thus seems as if the effect of filter-paper upon the surface-tension of water — fresh water or sea-water — might be due to some substance which is not completely removed by ether, but which contaminates the water-surface.[1] My experience is that the softest and most porous filter-paper produces the greatest reduction of the surface-tension, while the harder kinds, especially those treated with sulphuric acid, have less effect.[2]

In order to examine whether other porous substances had a similar effect, I immersed pieces of ordinary charcoal and plates of porous porcelain or earthenware in water with a maximum of surface-tension, but no indication of reduction was observed. Filter-paper which had been carbonized, by being heated in carbonic acid, had absolutely no reducing effect upon the surface-tension of water, and had totally changed its nature in this respect. Filter-paper repeatedly heated over a flame until nearly ignited, had the same reducing effect as before.

Thin plates of asbestos felt which had not been cleansed, had a reducing effect upon the tension of a clean water-surface when immersed; but after the same plates had been dried and well heated over a Bunsen flame, they had no reducing effect. If they were now immersed in water with a contaminated surface, they would at once increase its tension towards a maximum, and I found this a convenient method of cleaning a water-surface.

Quincke states that the tension of a free surface of alcohol is reduced from 5 to 10 per cent, if it be left undisturbed for some time. This did not

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[1] Experiments made after the above had gone to press, prove, however, that the ether, by evaporation, may actually leave a residuum which reduces the surface-tension of water. Plates of thin asbestos felt were well freed from all greasy matter by heating over a Bunsen flame. They were then soaked with ether, and were afterwards dried by evaporation. These plates immersed in water with a clean surface reduced the tension of the latter to some extent, which proves that a residuum, probably greasy, has been left by the ether.

[2] *Röntgen* says (Wied. Ann. der Phys. und Chem. vol. 46, 1892, p. 15): "Reines, unberührtes Filtrirpapier aus der Mitte eines grösseren Paketes genommen, verunreinigt die Oberfläche nicht, dagegen unter Umständen wohl solches, das längere Zeit an der Luft gelegen hat". Röntgen speaks here of mercury. I have not yet been able to find any filter-paper that does not lower the tension of a water-surface as long as it remains immersed in the water.

coincide with my observations (see p. 60) and, therefore, in order to decide the question with absolute certainty, I made some new investigations.

Alcohol of 95 % was poured into my experiment-vessel (see description, pp. 55 & 56), and was left there for two days; but not the slightest change in the surface-tension could be observed, except what was produced by the changes in temperature. The following determinations of the surface-tension were made:

	Temperature of Alcohol.	Weight of Meniscus round suspended Platinum Plate.	Value of Surface-Tension α mg./mm.[1]
Surface of alcohol freshly exposed	12 ° C.	131 mg.	2·46
After 21 hours, surface undisturbed	8·3 -	135 -	2·54
After 24 hours, surface undisturbed	8·1 -	135 -	2·54
After 47 hours, surface undisturbed	13·9 -	129·8 -	2·44

Even after the surface of alcohol had been standing undisturbed for 47 hours, it was absolutely impossible to produce the slightest change in the surface-tension either by contraction of the surface or by expansion, or even by skimming it. If a change in its tension of as much as 0·009 of the value (α mg./mm.) had been produced in this manner, it would have reduced or increased the weight of the meniscus round the platinum plate as much as half a milligram, and would have been distinctly visible. It will thus be seen that the tension of a free surface of alcohol of 95 % is not reduced as much as 0·009, or 0·4 %, after 47 hours; for if it had been reduced, it would probably be still more reduced by contraction of the surface, or at all events it would necessarily be again increased when the exposed surface was extended or skimmed, so that a new surface was exposed. These facts prove the correctness of the conclusion that the surface-tension of alcohol has no progressive diminution, and the apparent reduction of from 5 to 10 % observed by Quincke must have some other explanation.

[1] These determinations are not made with sufficient accuracy to claim much value as final determinations.

This result also agrees well with the observations by Plateau, Lord Rayleigh and others, that alcohol has no "superficial viscosity", and that a compass needle has always a constant time of vibration on the surface of alcohol[1], which would be absolutely impossible if the tension of a recently-formed surface had the slightest progressive diminution. But this also proves that the theory of an elastic after-effect in liquids is not tenable (cf. p. 43).

Concluding Remarks.

My various experiments have consequently led me to the conclusion that the changes in the surface-tension of water and aqueous solutions (as well as mercury) are caused by a film, which is gradually formed on any free surface of these liquids, and which is, as a rule, composed of greasy matter.

But whence is this greasy matter derived? From the air, the vessels and instruments employed, or from the liquids themselves?

Various observers seem to be of the opinion that it is derived from the air. Röntgen found[2] that an open, unprotected surface of mercury is rapidly contaminated — in half a minute —, while from 3 to 5 minutes will elapse before a clean surface, well protected by a watch-glass, will be sufficiently contaminated to prevent a water-drop from spreading over it. Röntgen believes, therefore, that the principal source of the contamination must be the atmosphere, and not the walls of his glass vessels. In a previous paper,[3] he also expresses the same opinion with regard to the source of the contamination of free water-surfaces. Quincke[4], however, has already observed that even well-protected water-surfaces exhibit a progressive diminution of their tension; and both Lord Rayleigh[5] and Volkmann (see above, p. 47), therefore feel inclined to believe that the water-surface is gradually contaminated by a layer composed of matter "supplied from the interior" of the liquid. Rayleigh considers this matter to be greasy, and he says besides that "the liquid is

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[1] See Lord Rayleigh, Proc. Roy. Soc. London, vol. XLVIII, 1890, p. 134.
[2] Wied. Ann. der Phys. und Chem., vol. XLVI, 1892, p. 155.
[3] Wied. Ann. der Phys. und Chem., vol. XLI, 1890, p. 329.
[4] Pogg. Ann. der Phys. und Chem., vol. CLX, 1877, p. 580.
[5] Proc. Roy. Soc. London, vol. XLVIII., 1890, p. 135.

also almost certain to receive contamination from the solid bodies with which it comes into contact."

At first I considered it probable that in all kinds of water, whether distilled or not, minute quantities of greasy matter are always present, probably derived from the organic life, the vegetation on land, and the vegetable and animal life in the water itself. This greasy matter may be dissolved in the water, or more probably in most cases is suspended in an extremely fine state of subdivision as a kind of emulsion. If the liquid stand undisturbed for some time, the suspended minute particles of greasy matter will gradually rise to the surface, and form an invisible and immeasurably thin film with a lower tension. If the surface be unprotected, the gradual formation of this layer may be accelerated by the evaporation of the liquid.

The following experiment proved, however, clearly that this view was untenable. A small cup of platinum was cleansed and heated to redness over a Bunsen flame. It was touched only with forceps which had previously been carefully heated. The cup was completely filled with tap-water, after the water had been running from the cock for hours. The surface of the water in the cup was skimmed with a platinum plate that had been previously ignited. The cup was now placed in the glass case of the balance, on a plate of asbestos felt, previously well heated over a Bunsen flame, and this plate was placed on a ring of sheet brass previously heated to redness. The platinum plate covered with platinum-black, after having been heated to redness, was suspended under the balance, so that its lower edge just touched the surface of the water in the platinum cup. The weight of the meniscus round the lower edge of the platinum plate, which was 26·6 mm. broad, was measured at intervals, and the following observations were taken:

	Weight of Meniscus.	Value of α mg./mm.
Just after the platinum plate had been immersed	402 mg.	7·56
After the water-surface had been once more skimmed with the platinum plate, previously heated	402 -	7·56
After 1 hour, 10 minutes, standing at rest	400 -	7·52
After 3 hours, — — temperature = 15·5° C.	401 -	7·54
After 25 hours, — — — = 13·6° C.	402 -	7·56
After $26^1/_2$ hours, — — — = 16·5° C.	400·5 -	7·53

	Weight of Meniscus.	Value of α mg./mm.
After 48 hours, standing at rest . . . . temperature = 15·5° C.	401 mg.	7.54
The platinum cup was now touched outside with greasy fingers.		
After 50 hours, standing at rest . . . . temperature = 16° C.	401 -	7·54
After 72 hours, — — . . . . — = 15·2° C.	402 -	7·56
The door of the glass case of the balance was left open for 10 hours to give the dust of the atmosphere free admittance.		
After 82 hours, ... temperature = 13·5° C.	402 -	7·56
A few drops of oil were placed on the outside of the platinum cup.		
After 96 hours, ... temperature = 17° C.	397 -	7·48
After 101 hours, ... temperature = 16·5° C.	397 -	7·48
The upper edge of the platinum cup was oiled with the finger in several places.		
After 106 hours . . . . . temperature = 14·3° C.	400 -	7·52
After 120 hours . . . . . temperature = 13·7° C.	402 -	7·56
After 150 hours . . . . . temperature = 15° C.	399 -	7·50

The temperature was measured by a thermometer suspended inside the glass case of the balance. During the first three observations, the temperature was not measured. During the first two observations, it was comparatively low, as the water was freshly drawn. At the third observation the temperature had risen, as the sun, through the window, had reached the glass case of the balance.

We see that there are no variations of the surface-tension of the water, except what are caused by the changes in temperature. There is consequently not the slightest indication of the progressive diminution of the surface-tension, even after 120 hours. If minute quantities of greasy matter suspended in the water were the cause of the variations in its surface-tension under ordinary circumstances, we should necessarily also have observed the same variations in this case. The water-surface was not protected, and evaporation therefore took place to such an extent that the quantity of water was greatly diminished during the six days. If the dust of the air were the cause of the progressive diminution of the surface-tension under ordinary circumstances, we should also have had the effect in this case; for the experiment was not different in this respect from previous experiments where a marked progressive diminution of the surface-tension always occurred.

We see that even after the upper edge of the platinum cup had been oiled, there was no appreciable reduction of the surface-tension for two days.

The oil appears to spread very slowly over the clean platinum surface, the reason perhaps being that this surface was not smooth.

This experiment proves clearly that under ordinary circumstances the solid bodies, especially the vessels, are covered with a thin layer of greasy matter, even though they may be carefully cleaned, but not heated, And from the solid bodies, especially from the vessels in which the aqueous liquids are contained, this greasy film will gradually spread over the liquid surface and reduce its tension. *The experiment proves,* moreover, *that the contamination producing the progressive diminution of the tension of aqueous surfaces is, under ordinary circumstances, derived solely from the solid bodies, especially the vessel, with which the liquids come into contact.*

In the case of liquids such as caustic soda, potash, or ammonia, the greasy contamination derived from the walls of the vessel, is at once converted into soluble soap which spreads over the surface; and the probability is that a viscous surface-pellicle is rapidly formed, similar to that which is formed on the surface of regular solutions of soap or oleate of soda.

It is mentioned on p. 63 that by dipping the fingers in the water — fresh water or sea-water, — or by adding a drop of oil to its surface, the tension is lowered to very nearly the same minimum as that obtained by contraction of a surface which has been free for some time. This fact certainly favours the view that it is actually greasy matter which generally forms the contaminating film with the low surface-tension.

There is, however, a striking difference in appearance between a water-surface contaminated to saturation with a layer of oil, and a surface whose tension is reduced to the same minimum by contraction, for in the former case the characteristic colours are distinctly visible, while it is not possible to produce any change in the appearance of an ordinary water-surface by contraction. This seems to indicate that the greasy matter must here be present in another state, probably as acids which are soluble to some slight extent. Lord Rayleigh's investigations on the reflection of light from clean, or contaminated, liquid surfaces in the neighbourhood of the polarizing angle[1], prove, that the optical properties of a water-surface are changed by the pro-

[1] Philosoph. Mag., vol. XXXIII, 1892, p. 1.

gressive contamination, and in a manner similar to that with oil. This fact also points strongly to the same conclusion that the ordinary contamination is composed of greasy matter.

The condition for the formation of a film of grease of this kind on a liquid, is, however, as mentioned above, that the greasy matter shall have a lower surface-tension than the liquid, and this is the reason why there is no progressive diminution to be observed under ordinary circumstances in alcohol, ether, carbon bisulphide, benzine, oil of turpentine, etc.

If the contaminated surface of an aqueous liquid be extended, the layer of contamination will be attenuated, and the surface-tension is increased; but if the surface be contracted, the layer is made thicker, and the tension is lowered. If, however, in the latter case, the contracted surface is left undisturbed, it might be expected that the layer of contamination would remain the same, or at least could not again be attenuated as long as the surface is not disturbed. Previous authors, *e. g.* Lord Rayleigh[1], have also expressed themselves to this effect. Nevertheless my observations seemed to indicate with certainty, as mentioned before (p. 38), that the tension of an undisturbed surface such as this, gradually increases as time passes, until it reaches a certain mean value. In order to settle this question beyond doubt, I made a broad flexible hoop of thin sheet brass[2]. This hoop was placed in a shallow china dish filled with ordinary tap-water, so that the edge of the hoop projected 3 or 4 cm. above the water-surface. After having been left undisturbed for 14 hours, the tension of the water-surface enclosed within the hoop had been reduced from 7·5 to 7·03. By slowly compressing or contracting the hoop, the area of this water-surface was now gradually very much diminished, and the surface-tension was thus reduced to 4·43. This contracted water-surface was now left absolutely undisturbed in this state, and its tension was examined at intervals by weighing the platinum plate (26·6 cm. broad and covered with platinum-black) immersed in it, and I found:

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[1] Proc. Roy. Soc. London, vol. XLVIII, 1890, p. 129 *supra*.

[2] I find that a similar arrangement has been used by Lord Rayleigh (see Philosoph. Mag., vol. XXXIII, 1892, p. 4) for skimming the water.

	Weight of Meniscus round Platinum Plate.	Value of Surface-Tension α mg./mm.
At beginning of experiment, after contraction of surface.	235 mg.	4·43
After 2 hours	270 -	5·07
— $7^3/_4$ hours (from beginning)	302 -	5·68
— $10^1/_4$ — — —	307 -	5·77
— 22 — — —	309 -	5·81
— $23^1/_2$ — — —	309 -	5·81
The hoop again opened out.	390 -	7·33

The temperature of the water was between 11·2° C. and 12·5° C. As the inner wall of the hoop was dry above the water-surface there seemed to be little probability that the film of contamination on the contracted surface within the hoop, could gradually extend over the surface of the latter, or could reach the water-surface outside the hoop and thus be attenuated. Nevertheless we see that the surface-tension gradually increases, according to a distinct asymptotic curve; it increases more and more slowly as it approaches a certain mean value, which is about 5·81, or about ·77 of that of a clean surface. It is nearly intermediate between the minimal value 4·43, and the maximal value 7·5. This result agrees well with my previous observations made with the hydrometer, and it thus seems as if the tension of a free water-surface has a tendency to approach gradually towards a mean value, after it has been either lowered to a minimum or increased to a maximum. This mean value varies according to the cleanness of the surface of the vessel, etc., but it seems, under ordinary circumstances, to correspond approximately with the point of contamination at which the motion of scraps of camphor on a water-surface very nearly cease, or still better, that at which drops of oil no longer spread. Lord Rayleigh has found the ratio of the tensions of a clean surface and a surface contaminated to the above degree, to be ·71 or ·72[1].

A state of perfect equilibrium evidently implies a certain concentration of the contamination of an aqueous surface, and the degree of this concentration will probably depend upon the cleanness of the solid surfaces, with

[1] Philosoph. Mag., vol. XXX, 1890, pp. 398, 400.

which the liquid is in contact. If the film contaminating the liquid surface be concentrated, *e. g.* by contraction, so much that its tension becomes lower than that of the contaminating film covering the solid surface, I consider it probable that it will spread over the latter until an equilibrium is again established. But if, on the other hand, the contaminating film of the liquid-surface be attenuated so that its tension becomes higher than that of the contaminating film of the solid surface, the latter will spread over the liquid surface until an equilibrium is reached.

Postscript. After the above had gone to press, further experiments were made on the progressive increase of the surface-tension of a contaminated water-surface. The tension of a water-surface that had been standing undisturbed and exposed to the air for 8 days was still 7·22; by contraction, the tension of this surface was, however, reduced to 3·95. By placing two drops of oil on a clean water-surface, its tension was reduced to exactly the same value of 3·95. A water-surface that at first had a tension of 5·4, had a tension of 6·58 after standing 5 days at rest and exposed to the air, and after 2 days more, the tension was exactly the same. A water-surface which to begin with had a tension of 5·64, after 10 days had a tension of 7·14, and by skimming the surface, its tension could be increased to 7·61. The evaporation from the water-surface had been considerable during all the experiments. Nevertheless we see that in these cases the surface-tension of the water increases, by standing, to much higher values — 7·22, 6·58, and 7·14 — than in the case mentioned on p. 72 (see also p. 38), where it only reached 5·81 (after one day). The explanation is evidently that in the above cases the china dish holding the water, had been carefully rinsed in running water for hours before the experiments, and the surface of the dish has therefore been more effectually freed from greasy matter than the hoop used in the experiment mentioned on p. 72. These experiments strengthen the explanation given above, that the state of equilibrium is a question of relation between the tension of the contaminating film of the liquid surface, and that of the solid surfaces.

The following experiment seems to prove this definitely. A platinum cup, previously heated to redness, was nearly filled with tap-water, the surface-tension of which was 7·60 at 18° C. The tension remained about the same

for two days. The surface of some tap-water which had been standing in a china dish for weeks, was much contracted, and with a glass rod, drops from this contracted surface were added to the water in the platinum cup. Thus the surface-tension of the latter was reduced to 6·77. The following observations were now made:

	Weight of Meniscus round Platinum Plate.	α mg./mm.
Just after α had been reduced; $t = 18{\cdot}5\,^{\circ}$ C.	360	6·77
After 1 hour; $t = 17{\cdot}7\,^{\circ}$ C.	380	7·16
After 24 hours; $t = 20\,^{\circ}$ C.	390	7·35
After 46 hours; $t = 20{\cdot}3\,^{\circ}$ C.	402	7·58

It is seen that in this case, where the vessel may be considered to be practically absolutely clean, the surface-tension gradually approaches very near to its maximum value again after having been contaminated, either because the contamination gradually extends over the clean platinum surface, or perhaps more probably because the contamination is gradually absorbed by the water, while no new contamination can be added from the clean platinum surface.

I was desirous of examining whether the surface tension gradually increased after having been lowered by the addition of oil or oily acids to the water-surface. A small area of a skimmed water-surface in a china dish was enclosed in an immersed hoop of sheet brass, previously heated to redness. The tension of this enclosed surface was reduced by a drop of olive oil to 5·2. After three hours, the tension had sunk to 4·7. After 19 hours and 22 hours, the surface-tension was exactly the same. The dry portion of the hoop projecting above the water, was now, however, covered with a greasy film, as drops of water would not immediately spread over its surface as they had done before, just after the hoop had been heated. There has evidently been too much oil on the water-surface to make it possible for the surface-tension of the water to be reduced. When the ring was lifted out of the water the oil spread over the whole water-surface, and the tension rose to 5.4.

If, in a similar experiment to the above, I added a drop of oleaginous acid to the pure water-surface enclosed within the heated hoop, the tension

was at once reduced to 4·42. The ring was now lifted out of the water, and the oleaginous acid spread over the water-surface, but the surface-tension remained the same. When this surface was much contracted, the tension was reduced to 3.76. When the surface was again extended, the tension remained the same. One hour later the tension had risen to 3·78, and after 23 hours it was exactly the same. The temperature was between 12° C. and 14·5° C. Also in this case, the water-surface was supersaturated, and the contaminating layer was evidently too thick to allow of the possibility of any gradual increase of the tension.

The last two experiments prove that the film of oily matter does not acquire its lowest tension immediately after having spread over the water-surface, but only after some time has elapsed, or after the surface has been extended and again contracted several times. It seems as if the oily matter must be somewhat mingled with, or perhaps to some slight extent dissolved by, the water on the surface, before the tension is reduced to a minimum.

In a similar way to the above, a pure water-surface was contaminated with drops of butyric acid and oleaginous acid, but with very nearly the same results. At first the surface-tension was reduced to 4·79, and after two hours it was 4·70. Three days later, the surface-tension had sunk to 4·51. After one day more, the tension was 4·64. Two days after this it was 4·70, and 6 days later still, or 12 days after the beginning of the experiment, the tension was again 4·79. The temperature was between 14° C. and 15·5° C. We see that during the first three days, the tension has been slightly decreasing, while it has increased to the same degree during the last nine days. In this case, the water-surface has also been supersaturated with contaminating greasy matter, and thus there could be no appreciable increase of the surface-tension.

I had found, as mentioned above, that alcohol and carbon bisulphide have generally no variations in their surface-tension, because this is so low that the contaminating matter cannot spread over their free surfaces. I was now desirous of examining how it was with other liquids with a higher surface-tension in this respect. I chose aniline, which I found to have a surface-tension of 4·47. This is a much higher tension than that of oil or greasy matter, and should therefore make it possible for grease to spread

over and contaminate the surface. At first I could produce no changes in the tension of a surface of aniline, neither by expansion nor by contraction. After the surface had been touched with a glass rod dipped in oil, changes in the tension of as much as 2 or 3 % of the value could be produced. After a while, the changes were again much reduced. That the aniline surface really could be contaminated with a film reducing its tension was also proved by the fact that motes moved before an advancing platinum plate, although of course not to the same extent as on a water-surface.

I had previously found that the immersion of a body with a dry surface would generally increase the tension of a contaminated water-surface by attenuating the film of contamination. By new experiments I found, however, that if the smooth surface of the solid body were perfectly wetted by the water, *i. e.* were absolutely freed from all greasy matter, its immersion had no effect upon the surface-tension of the water. The tension of a contaminated water-surface was reduced to a minimum by contraction into a small area. A platinum plate, previously cleaned and heated to redness, was immersed, but had absolutely no effect upon the surface-tension. This proves that the immersed portion of the clean platinum plate is not covered with the contaminated water-film. A plate of sheet brass, cleaned and heated in the same way, was immersed, and actually had a slight increasing effect upon the surface-tension, but so slight as to be only just perceptible. The explanation is probably that the surface of the brass had been corroded, and was not so smooth as that of the platinum; it has therefore been able to carry down with it some part of the contaminating surface-film of the water. After this brass plate had been dried and touched all over with the fingers, its immersion increased the tension of the contaminated water-surface considerably more. The dry platinum plate touched all over with fingers, would, however, lower the surface-tension appreciably when immersed. The reason is evidently that the smooth platinum surface readily gives off its greasy coating to the water-surface, while this is not the case with the rougher, corroded brass surface. On the contrary, the thin greasy coating on the latter increases the friction between it and the water-surface, and more of the contaminating surface-film of the water is therefore carried downwards with the plate than when it is pure.

After the greasy platinum plate had been dried and rubbed with filter-paper, it would also increase the surface-tension of the water by immersion. That the plate was not absolutely free from all greasy matter was proved by the fact that the water did not cover it uniformly, but formed drops on its surface. When the plate was again dried and heated to redness, it had no effect upon the surface-tension of the water when immersed.

IV.

DETERMINATION OF THE SPECIFIC GRAVITY OF THE SEA-WATER BY ORDINARY FLOATING HYDROMETERS, AND BY HYDROMETERS OF TOTAL IMMERSION.

The preceding chapters elucidate the nature of the great and often uncontrollable variations in the surface-tension of water and aqueous solutions. We have found that these variations are caused by greasy contamination of the liquid surface, generally derived from the surfaces of the solid bodies with which the liquids come into contact (see p. 69). Our investigations prove, moreover, that these variations are, as a rule, the chief causes of the uncertainty and inaccuracy in most determinations of the specific gravity of fresh water, or sea-water, made with ordinary hydrometers. If any high degree of accuracy is to be attained in this kind of determination, it is absolutely necessary that the stem of the hydrometer be always perfectly wetted, so that the angle of contact is zero, or at least always identical, but it is still more important that the value of the surface-tension of the liquid is accurately known at the moment of the reading of the hydrometer[1]. As

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[1] After the above had been written, I saw that Signor Guglielmo has suggested a very simple method of determining the effect of the surface-tension upon the hydrometer. (Rendiconti della Reale Accad. dei Lincei, Ser. 5, vol. VIII, December, 1899, pp. 342—344). He simply immerses in the surface-water a glass tube with an inner diameter equal to the diameter of the stem of the hydrometer, and he measures the height to which the water rises in the tube. This height should be equal to the amount that the hydrometer is lowered by the surface-tension. I think the method is an improvement, but it is not satisfactory. for there will generally be differences between the surface-tension of the water in the tube, and that of the water-surface surrounding the stem of the hydrometer.

If the determinations are made in a laboratory on land, where a balance can be used, I would strongly recommend the determination of the surface-tension of the

these conditions, and especially the last one, are not, as a rule, sufficiently considered, most determinations of the specific gravity of sea-water, hitherto made with ordinary hydrometers, of constant weight, or of variable weight as recommended by Buchanan, may have considerable errors, the magnitude of which will be smaller, the smaller the diameter of the stem as compared with the volume of the body of the hydrometer.

If, for instance, we take hydrometers such as those of the so-called large set for scientific investigations made by Dr. Küchler in Ilmenau, we shall find that the disagreements in the indications of these instruments caused by variations in the surface-tension of the sea-water, may amount to 0·000 3 of the specific gravity $\left(S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}\right)$. The stems of some such hydrometers before me have a diameter of nearly 2·9 mm. The scale of the stem is graduated to 0·0001 of $S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$. The distance between the division marks is 1·67 mm. The weight of the meniscus will consequently, at a maximum of surface-tension of the sea-water (equal to 7·7), lower the hydrometer about 68 cubic mm., or a little more than 10 mm. in height, which is equal to 6 degrees of the scale, or 0·0006 of the indication of the instrument. At a minimum of surface-tension (equal to about 3·8), the indication of the same hydrometer will, however, only be lowered 0·0003 by the surface-tension. A diminution of the surface-tension of the sea-water from maximum to minimum will consequently cause a difference in the indications of the hydrometer of no less than 0·0003 of $S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$. Under ordinary circumstances, the variations in the surface-tension of the water-samples examined will not be as much as this. But even with the very greatest degree of cleanliness, it is impossible to avoid the occasional occurrence of variations in the surface-tension sufficient to alter the indications of the above instruments as much as 0·0002 of $S\frac{17{\cdot}5^{\circ}\text{ C.}}{17{\cdot}5^{\circ}\text{ C.}}$[1], if no special care be taken to cleanse the water-surface before the observations are made. It should, for example, be remembered that if

water simply by immersing a platinum plate, previously heated to redness, in the water-surface, and then weighing the meniscus round the plate, as described on pp. 56, 61. This simple operation, which requires little time, will actually give the tension of the water-surface surrounding the hydrometer-stem, and will enable one to correct the simultaneous reading of the hydrometer very accurately.

[1] It is here taken for granted that the stem of the hydrometer is perfectly wetted. But as this is not generally the case, the errors may even be considerably greater.

the instruments and towels used have been washed with soap, and all traces of the soap are not carefully removed by rinsing, etc. this is certain to lower the surface-tension, perhaps considerably, and may thus cause considerable errors in the observations. If the towels have been touched with the hands before the hydrometer or the inner wall of the glass cylinder is wiped, this may also cause errors. And moreover, the surface of a glass instrument wiped with these towels will not be perfectly wetted by the water. That the water-surfaces generally operated with in observations with hydrometers, are not really clean, is also clearly proved by the observations of Makaroff, Krümmel and myself, that the immersion or removal of a thermometer in the water-sample may change the indications of the hydrometer considerably. These circumstances explain why there are so many apparently irregular variations in the specific gravity of the sea at different depths, according to most series of determinations made with the hydrometer on board, or even in the laboratory. The probability is that most of these apparently irregular variations are due to errors of observation.

If fairly accurate determinations of the specific gravity of the sea-water are to be obtained by the hydrometer, it is absolutely necessary to take special care that the observations are always made in precisely the same manner, and that the values of the surface-tension of the samples examined are uniform, both when the errors of the instrument are determined, and when the specific gravity of the various water-samples is observed. We have seen above (see p. 40) that it is comparatively easy to produce a maximum of surface-tension, viz. by extending or cleaning (skimming) the water-surface (p. 58), and that consequently the minimal indications of the hydrometer are most uniform and trustworthy.

I have found the following plan for making accurate observations with the hydrometer most convenient.

(1) In order to avoid the possibility of air-bubbles being formed in the water-samples during the observations, and adhering to the hydrometer, the samples, enclosed in bottles, are heated in an air-bath to some comparatively high temperature (25° or 30° C.); the superfluous air is driven out by shaking, while the bottles are opened for a moment, and then the samples are cooled down to the temperature at which they are to be examined.

(2) In order that the water-samples shall not alter their temperature too rapidly during the observations, I use a double Dewar's glass cylinder with vacuum-jacket. The cylinder is covered on one side with a silver mirror, while the other side is transparent, so that the hydrometer and thermometer may be read off there[1].

The diameter of the inner cylinder is about 5 or 6 cm. The inner wall is carefully cleaned with a solution of ammonia, or carbonate of soda, and is well rinsed in running water.

(3) A thin thermometer, graduated to 0·1° C., is immersed in the water-sample, to such a depth that its bulb is level with the centre of the body of the hydrometer when it is floating freely.

(4) The hydrometer is carefully cleaned from all greasy matter, by solutions of ammonia, or carbonate of soda, or by ether and alcohol, and is well rinsed, if possible in water of the same kind as that which is to be examined. By noting whether the water spreads evenly over the surface of the instrument, it is easily seen whether it is perfectly wetted.

5) The glass cylinder is so well filled with the water-sample to be examined, that when the hydrometer is immersed, the water forms a convex surface over the top of the cylinder. I find it convenient for this purpose either to fill the cylinder by means of an immersed siphon, or to have a hole at the bottom of the cylinder, to which an india-rubber tube is attached, communicating with a glass vessel filled with the water-sample. By lowering or raising this vessel, the level of the water in the cylinder may be altered at will.

The convex water-surface at the top of the cylinder is now perfectly cleansed by skimming. Two specially made plates of sheet-platinum (or sheet-brass) previously heated to redness, are placed in the surface-water one on each side of the hydrometer-stem, for which there is a recess in each plate to allow of their coming close together without leaving any water-surface between them. By moving these plates rapidly outwards towards the

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[1] If a cylinder of this kind is not at hand, it is very convenient to place the glass cylinder containing the water-sample in which the hydrometer is floating, in a wider glass cylinder with water of exactly the same temperature as the water-sample. In this manner, the temperature of the latter may be kept practically constant for some length of time, or, at any rate, the changes in the temperature will be very slow (cf. p. 6).

sides, over the top of the glass cylinder, the whole of the water-surface is perfectly skimmed and renewed. The level of the water is then rapidly lowered a little in the cylinder, and the indication of the hydrometer is at once read off under the water-surface. In this manner one may feel certain that the observation is really taken at the maximum of surface-tension, and if the operation be repeated several times with the same result, one may be certain of having obtained the specific gravity of the water-sample with an accuracy of at least $\pm 0{\cdot}00002$, provided that the hydrometer is fairly sensitive, and that its error has been determined by the same method in water, the specific gravity of which was accurately known.

If the above method of cleaning the water-surface be thought too complicated, a much simpler, although not quite so certain, method is to immerse a number of dry, clean slips of writing-paper, and again remove them before each reading of the hydrometer. An excellent and more certain method is to use for the same purpose pieces of thin asbestos-felt or asbestos-cardboard, which have previously been rinsed in distilled water and dried, and then well heated in a smokeless flame. An excellent method is also to produce violent disturbances of the water-surface by shaking the glass cylinder (see p. 21), and I recommend this to be done after having cleaned the surface well with immersed paper or asbestos-felt.

Various methods have been suggested in order to correct or avoid the disturbing influence upon the hydrometers of the variations in the surface-tension, *e. g.* by *Marangoni*, *Sandrucci*[1], *O'Toole*[2], *Lohnstein*[3]. Lately a very ingenious method, based upon the principle of Lohnstein, is suggested by *G. Guglielmo*[4], and may be used both for hydrometers of constant weight and of constant volume.

None of these methods, however, will allow of a very high degree of accuracy, hardly higher than may be attained by the method recommended above, nor are they very convenient for use on board ship in the open sea.

If such a high degree of accuracy be desired in the determinations made on board ship of the specific gravity of sea-water, as, in my opinion,

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[1] Nuovo Cimento, 1895.

[2] The Scientific Proc. of the Roy. Dublin Soc., vol. VIII, 1898, p. 753.

[3] T. Lohnstein, Zeitschr. für Instrumentenkunde, vol. XIV, 1894, p. 164; Wied. Ann. der Phys. und Chem., vol. XLIV, 1891, p. 52.

[4] G. Guglielmo, Rendiconti della Reale Accad. dei Lincei, Ser. 5, vol. VIII, 1899, pp. 344—347.

should be demanded in future oceanographical work, I think it is quite necessary altogether to exclude the effect of the variable surface-tension, as well as other disturbing influences of the water-surface. This can easily be done by totally immersing the hydrometer in the water, and if the weight of the instrument, its volume, and the exact temperature at which it just sinks and rises in the liquid be exactly known, the specific gravity of the liquid may be determined with a very high degree of accuracy.

In discussing the subject a year or two ago, Prof. Sophus Torup and I were struck with the idea of trying some new methods based upon the above principle. We have since found that these very methods had already been suggested by Prof. *Pisati,* and were described in 1890 by *N. Reggiani*[1] who used hydrometers of total immersion, both with constant and variable specific gravity, on board the 'Washington' of the Royal Italian Navy, in the Mediterranean, in 1883. Reggiani did not go beyond determining the specific gravity of the water-sample to four places of decimals.

It is most astonishing that so little attention has hitherto heen paid by oceanographers to this valuable method.

While referring the reader to Reggiani's important paper, I shall here only shortly mention the methods employed by Torup and myself.

Prof. Torup uses a set of small glass hydrometers or floats of total immersion, with constant specific gravity, which is somewhat lower than that of the sea-water to be examined. Enclosed in each hydrometer is a thermometer, with the bulb projecting at the lower end of the instrument. Thus the temperature of the water in which the hydrometer is floating is easily determined. The temperature of the water is kept as constant as possible during the observation, by a water-jacket. The observer now ascertains how much distilled water of a known temperature he must add to a certain volume of the sea-water in order to give it the same density as the hydrometer. Knowing the weight and volume of the instrument he also knows the density of the liquid — which of course is carefully stirred — and can calculate very accurately the specific gravity of the original sea-water. If he makes the hydrometer again rise and sink a few times by alternately adding minute quantities

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[1] Rendiconti della Reale Accad, dei Lincei, Ser. 4, vol. VI, 1890, p. 99.

of the sea-water and distilled water, he may materially increase the accuracy of his determination.[1]

My method is somewhat different, and corresponds to the second method described by Reggiani, ("areometri a densita variabile"). A year ago I had three hydrometers of total immersion made of Normal Jena Glass No. 16^{III}, their specific gravities $\left(S\frac{17{\cdot}5^0\,\text{C.}}{17{\cdot}5^0\,\text{C.}}\right)$ being about 1·023, 1·024 and 1·026. The cylindrical body is 3·5 cm. in diameter, and 15 cm. long. The stem is 3 cm. long, and 1·5 mm. in diameter, and has a scale graduated in mm. The observations are made in a Dewar's cylinder (surrounded by a vacuum-jacket, see fig. 2) of the same description as that mentioned on p. 81, or in a glass cylinder placed in a wider cylinder containing water (see p. 81, footnote), the latter method, however, being less convenient if the temperature of the sea-water is to be changed at will during the observations. The sea-water, at certain intervals, is well stirred in order to give it a uniform temperature all through. That this is done is easily ascertained by three thermometers placed in the cylinder with their bulbs respectively in the upper, intermediate and lower strata of the water. By these thermometers, the temperature of the water can easily be determined at least to within $\pm\,0{\cdot}01^0$ C.[2]

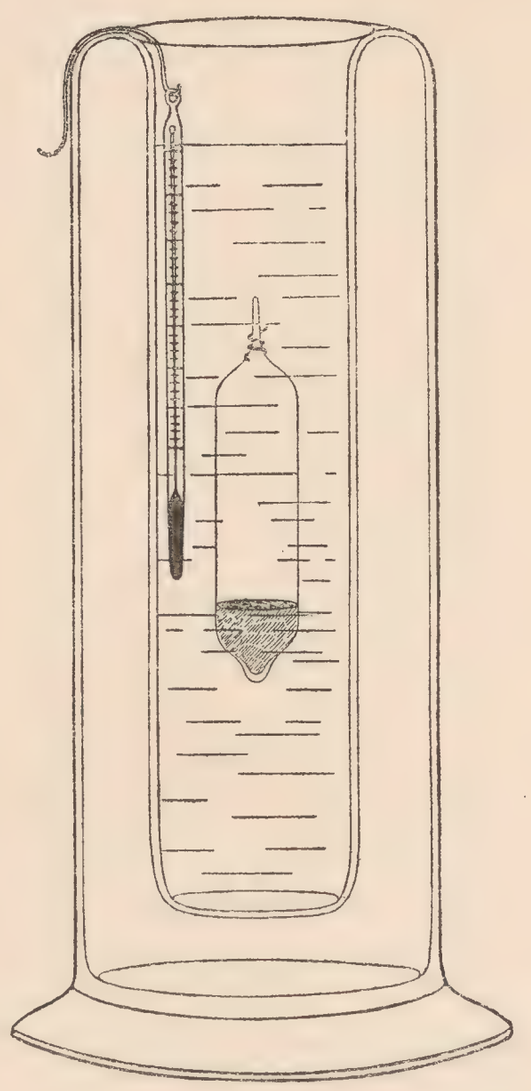

Fig. 2.

If very accurate determinations are desired, the observations should be made at temperatures which are as nearly as possible the same as that to which the hydrometers have been exposed for some time previously; for glass instruments do not assume their final volume until some time after their temperature has been changed.

When the hydrometer suitable for the water-sample in question, is immersed, I at once obtain a fairly accurate determination of the specific gravity

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[1] Prof. Sophus Torup will shortly publish his results in 'Nyt Archiv for Mathematik og Naturvidenskab', Christiania.

[2] In one of my hydrometers for total immersion, I have also a thermometer enclosed with projecting bulb, but I find this an unnecessary encumbrance.

of the water by the indication of the stem, and I see approximately how much the instrument must be loaded, in order just to sink it in the water. This point is attained by placing small spiral-shaped weights of platinum or platinum-iridium round the stem (see fig. 2). I use, for this purpose, a set of weights down to 2 or even 1 mg. By now alternately lowering and raising the temperature of the water-sample a trifle, several times[1], I can make the hydrometer alternately rise and sink, and can determine to a high degree of accuracy the temperature at which the water and the instrument have exactly the same density, *i. e.* the temperature at which the hydrometer will remain poised at some intermediate depth in the water, as there is generally a trifling difference in temperature above and below.

If we know the absolute weight of the hydrometer *in vacuo*, its volume, and the specific gravity or volume of the platinum-iridium spiral weights, we may determine the density of the water at this temperature, with an unusually high degree of accuracy. If one has a sufficiently large set of hydrometers of this kind, with small differences between the specific gravity of each, the small spiral weights can also be dispensed with, and the determinations obtained merely by raising or lowering the temperature of the water-samples; but I think the use of weights is more convenient and quicker.

In the above manner, the specific gravity of the water can, with tolerable ease and rapidity, be determined with absolute accuracy to at least five places of decimals, and if special care be taken, to even the unit of the sixth decimal place.

This method has the advantage of being capable of employment on board ship in the open sea, and even more easily, and with much greater certainty, than the ordinary hydrometer. We have here only the thermometer to read off, which is easy, while it may be no easy task to read off an ordinary hydrometer accurately in a heavy sea.

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[1] A convenient method for lowering the temperature of the water-sample is to immerse a closed glass tube filled with ice-water; and for raising the temperature, to immerse a glass rod, heated over a lamp, or a closed glass tube filled with warm water. The water-sample is of course well stirred each time. The changes in temperature should not, however, be great, as the glass hydrometer assumes its final volume corresponding to the new temperature comparatively slowly. Prof. Torup proposes a very convenient method of raising the temperature of the water, by placing near the bottom of the cylinder a spiral of thin platinum wire, which may be heated by an electric current.

One great advantage of this method is that errors caused by the surface-tension of the water are totally excluded, and if the specific gravity is to be determined only to the fifth decimal place, no extraordinary amount of cleanliness is necessary. Even if the hydrometer be handled with greasy fingers, it will hardly cause an error in the determination of the specific gravity of as much as 1 in 100,000.

Some months ago, I had some new total immersion hydrometers made both of Jena Glass No. 16^{III}, and of No. 59^{III} (borosilicate). The advantage of the latter kind of glass is of course that the coefficient of thermal expansion is so small — only 0·0000177 —, and that its secular contraction may be reduced almost to a negligible minimum by boiling the instrument for some time. Thus the accuracy of the determinations are not so much impeded by greater variations in the temperature during the observations. Some of the hydrometers are of about the same size and shape as those mentioned above, only the stem is shorter, being about 1·5 cm. long; and some of them are of smaller volume, for use when only a small quantity of water is available for the determination. Their specific gravity is equal to that of distilled water at about the ordinary temperature of a room. This has the advantage of allowing the volume of the instrument to be easily determined at any time, even on board ship, provided that its weight *in vacuo* is accurately known. It is only necessary to determine very accurately the temperature at which the hydrometer sinks or rises in distilled water, and the correction of the instrument may always be controlled, provided that pure distilled water can be obtained. The drawback is, however, that these instruments must be heavily loaded with platinum weights in order to reach the specific gravity of sea-water; and the volume of the platinum weights must then be very accurately determined, if a high degree of accuracy is to be attained.[1]

[1] Instead of the spiral weights round the short glass stem of these hydrometers, we may use a ring with a short graduated stem of platinum wire, say 2 or 3 cm. long, projecting above the water. At the upper end of this platinum stem is a horizontal plate for holding the weights with which the instrument is weighed down to a certain mark on the stem. Thus these instruments may be transformed into very sensitive floating hydrometers of constant volume and of variable weight, which will be only slightly influenced by changes in the surface-tension, as the diameter of the platinum stem need not be more than 0·5 or 0·7 mm. If this stem be covered with platinum-black, and first boiled in distilled water and then heated to redness before use, it is easily ascertained that it is clean, and perfectly wetted by the water. In this manner the specific gravity of the sea-water may conveniently be determined with an accuracy of 1 in 100 000.

On the whole, I think the method with hydrometers of total immersion is to be recommended. After a little practice, I think the method of those observations might be so arranged that they should not take much more time than ordinary determinations with the hydrometer, if the latter were to be made fairly accurately. In my opinion, the method promises to become important for future oceanographic work, as it should enable us to determine the density and salinity of the ocean with a considerably higher degree of accuracy than has hitherto been reached. And it excludes, even in the case of less skilful investigators, the chief source of error, vitiating, under ordinary circumstances, all observations made with the common hydrometer.

Postscript. As this is going to press, I find in the December number of the 'Philosophical Magazine' (London, 1899) a paper by *Arthur W. Warrington* on "Hydrometers of Total Immersion"; in which a hydrometer and a method of determining the specific gravity of water, almost precisely similar to the above, are described. The author does not, however, seem to know that the same method has already been suggested by Pisati, and described by Reggiani. Warrington finds the method exceedingly delicate, and claims that for determinations of the specific gravity of liquids, "the results are accurate to 1 in 1,000,000." He says that "the observations were repeated with the temperatures rising or falling . . . . ., until two temperatures, differing only by a few thousandths of a degree, had been obtained, at one of which the hydrometer was heavier, and at the other lighter, than the water." This gives an indication of the possible degree of accuracy of the method, although this degree cannot, under ordinary circumstances, be attained on board ship.

Godthåb, *April,* 1900.

FRIDTJOF NANSEN.

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